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MEMOIRS OF THE DEPARTMENT OF AGRICULTURE IN INDIA

MILLETS OF THE GENUS SETARIA IN THE BOMBAY PRESIDENCY AND SIND

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MILLETS OF THE GENUS SETARIA IN THE BOMBAY PRESIDENCY AND SIND.

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Sir J. D. Hooker, in his account of the grasses in the "Flora of British India," admits about 10 species in the genus Setaria of which seven are found in India and Ceylon. These are :—

(1) S. italica, *Beauv.*, is cultivated, throughout India and in most tropical and temperate countries.

(2) S. glauca, *Beauv.*, is cultivated, so far as we at present know, only in one part of the hill country in the Poona district, and, perhaps, also near Khanapur in the Belgaum district of the Bombay Presidency. As a wild grass, it is also distributed throughout tropical and temperate regions.

(3) S. intermedia, *Roem and Sch.*, and

(4) S. verticillata, *Beauv.*, are two very closely allied species, abounding during the rains in rich soil in low-lying places and often where refuse has been thrown, but useless as fodder on account of their harsh nature. Duthie, however, says of the latter that cattle will eat it when young, that is, before the flowering spikes appear and that the grain is eaten by poor people. Symonds remarks that cattle will not eat it, so it is considered a troublesome weed wherever found, and that it is common about rubbish heaps all over India.

(5) Sir J. D. Hooker is disposed to consider that S. viridis, *Beauv.*, is possibly the wild form of S· italica. This grass does not extend southwards so far as any part of the Bombay Presidency.

(6) S. gracillima, *Hook. f.*, is confined to Ceylon, and finally there is

(7) S. forbesiana, *Hook. f.*, which has been recorded from the Konkan by Lisboa.

The purpose of this note is to describe the two cultivated species of the genus as found in the Bombay Presidency only. The descriptions are founded on many plots of specimens raised from grain received from all districts during the seasons 1906-1907. The characters of the genus with its two species may be shortly expressed as follows :—

SETARIA.

Annual, tufted grasses. *Spikelets* smooth, one flowered, awnless, shortly stalked, articulate and clustered on the very short branches of a spiciform panicle, subtended by persistent involucels of few or many barbed bristles (barren branches) which are usually connate at the very base. *Glumes* 4, membranous, with the exception of IV, which becomes bony, I equal to $\frac{1}{3}$ III or shorter, II almost equal to IV, III neuter, paleate, IV at first coriaceous, becoming bony, plano-convex, bisexual, paleate, *pale* coriaceous, *stamens* 3, *styles* 2, distinct, penicillate at the tips. *Grain* small, free, but permanently enclosed within the thickened glume and pale.

A short, densely tufted plant, *spikes* erect, narrow. *Bristles* 6 to 8 below each spikelet. *Glume* IV transversely rugose . . . 1. S. glauca.

Taller, not densely tufted. *Spikes* usually nodding, broader and longer, *bristles* 1 to 9 below each spikelet. *Glume* IV quite smooth . . . . 2. S italica.

Spikes straw coloured ; with short or no bristles, secondary spikes arranged spirally, surfaces convex, their

breadth at the base of each branch more than ½ their length. . . . . 2 (a). S. italica (type).

Spikes straw-coloured, with long bristles, secondary spikes, too closely aggregated to show a spiral arrangement. . 2 (b). S. italica. *Var. nov.* barbata.

Spikes purple brown, uppermost branches only crowded, lower secondary spikes much laxer than in the last, their breadth at the base of each branch equal to ½ or less than ½ their length. . . . .
2 (c). S. italica. *Var. nov.* purpurea.

Spikes brown, crowded, cylindrical or slightly club-shaped, broad at apex, almost erect, bristles only slightly exceeding the spikelets. . . . . . .
2 (d). S. italica. *Var. nov.* typhoidea.

1. Setaria glauca, *Beauv., Agrost.* 51 ; *Hooker Fl. Br. Ind., VII, p.* 78 ; *Dalz. & Gibs., Bomb. Fl., p.* 293 ; *Duthie, Grasses of N. W. India, p.* 8 ; *Indigenous Fodder Grasses, pl. X ; Fodder Grasses of Northern India, p.* 14 ; *Lisboa, Bombay Grasses, p.* 33 ; *Mollison, Text Book on Indian Agriculture, III, p.* 67 ; *Symonds, Indian Grasses, p.* 42, *pl. XXVI.*

Vern.—Marathi (as a grain crop), *Barati ;* (as a grass) Hindustani, *Bandra, Bandri ;* Marathi, *Bhadli.*

One to two feet high, densely tufted. *Leaves* pale green, rather weak and narrow, smooth below, scabrous above, *ligule* minute, 3—4-sected. *Spikes* erect, yellow, narrow, completely cylindrical, the lower half often barren, 1 to 6 inches long by ⅜ inch broad, including the bristles which are yellow and ¼ inch long, pointing upwards, barbed, 6 to 8 in each spikelet. *Spikelets* ⅛ inch long, green, sessile on the slender axis of the spike. *Glume* I, minute, II equal to ½ IV, 3-nerved, III paleate equal to IV, which is coriaceous white and transversely rugose, its *pale* is also white.

Cultivated as a *kharif* crop in the Mulshi Petha of the Poona district, and probably also near Khanapur in the Belgaum district.

Mr. Mollison writes in his Text-book on Agriculture that "a good crop stands about two feet high. The plants have enormous tillering power. A thick crop can, therefore, be got from a small seed rate, provided the seed is equally scattered in sowing. The stalks are very fine, the leaf growth considerable and the fodder at least good. The outturn of fodder per acre is not, however, heavy. This grass is sparingly cultivated in the hilly parts of the Deccan on comparatively light soil with moderate rainfall. *Barati* is a rains' crop sown in June-July and reaped in October-November."

The grain of the wild plant is used as food in the Central Provinces and Chutia Nagpur.

Duthie says of the grass in a wild state that it is common all over the plains of India, and attains moderate elevations on the hills, and that it is generally considered to be a fairly good fodder grass. It thrives best on rich or cultivated ground. Symonds states that it appears a moderately good fodder, but is unsuitable for making hay. In Australia it is highly relished by stock. In the United States where it is known as "Pigeon or Bottle Grass," it furnishes fodder which is considered as good but less productive than that of "Hungarian Grass" (*S. italica*).

2. Setaria italica, *Beauv. Agrost., p.* 51 ; *Hook. Fl. Br. Ind., VII, p.* 78 ; *Duthie, Grasses of N. W. India, p.* 8 ; *Field and Garden Crops, part* 2, *p.* 5, *pl.* 25 ; *Fodder Grasses of Northern India, p.* 15.

Panicum italicum, *Dalz. & Gibs., Bomb. Fl. Suppl., p.* 98, ? Panicum pilosum, "Badlee," *id. l. c. p.* 98, ? P.—(?) sp. ("Rale"), *id. l. c. p.* 98.

2 (a). Setaria italica (type).

Attaining the height of 4½ feet. *Culm* yellow, moderately robust, *nodes* tumid smooth, *internodes* short, *sheaths* smooth, longitudinally close striate, margins ciliate, *ligules* $\frac{1}{16}$ inch long, irregularly partite or fimbriate. *Leaves* 12 to 18 inches long, by ½ to 1 inch broad, light green in color, linear lanceolate acuminate, base slightly suffused with brown, blade with both surfaces scabrous, midrib distinct, white, strong, lateral nerves

five on each side, weaker nerves numerous, indistinct, *flag* with a long sheath, *blade* shorter than or exceeding the inflorescence. *Peduncle* long and slender. *Spike* curved and nodding, up to $8\frac{1}{2}$ inches long, and $1\frac{1}{4}$ inch broad, including the very short bristles (which, however, in poor examples are often longer, while they are altogether wanting in the finest variety), lower branches only slightly scattered, upper densely aggregated, all distinctly arranged in a spiral manner with convex surfaces, *rachis* creamy white, densely white pilose. *Spikelets* subsecund on the branches, yellowish green, in clusters of 40 to 50, *bristles* few, white, only attaining $\frac{1}{8}$ inch in length, pointing upwards, *spikelets* ovoid, slightly constricted near base. *Glume* I equal to $\frac{1}{3}$ III, ovate, 3-nerved below apex ; *Glume* II shorter than IV, elliptic, 5-7-nerved ; *Glume* III almost equal to II, paleate, 5-7-nerved ; Glume IV *pale* yellow, protruding when ripe.

2 (b). Setaria italica, *Beauv. var. nov.* barbata.

This differs from the type described above in the following points :—

Spikes up to 9 inches long but usually much shorter, the two lowest branches often remote, the upper more densely aggregated and scarcely showing the spiral arrangement. *Spikelets* distinctly secund on the branches, in clusters of 12 to 16, *bristles* 3 to 9 at the base of each spikelet, $\frac{5}{16}$ inch long, often altogether absent in the uppermost spikelets. *Spikelets* $\frac{1}{8}$ inch long, constricted near the base. *Glume* IV *pale* white.

2 (c). Setaria italica, *Beauv. var. nov.* purpurea.

This differs as follows from the above named varieties :—

Internodes yellow, suffused with brown, bases of leaves distinctly brown. *Leaves* dark green. *Spikes* up to 9 inches long, the smaller sometimes erect, the larger invariably curved and drooping, *lower branches* slightly scattered, *central* loosely, and *uppermost* densely aggregated, *rachis* suffused with brown purple, densely setose with white hairs, secondary spikes dense, with about 20 spikelets in each, *bristles* usually single, almost $\frac{1}{2}$ inch long, brown, spikelets as above. *Glumes* I, II and III suffused

with purplish brown, IV bright yellow, ultimately becoming orange red. *Grain* white as usual.

2 (d). Setaria italica, *Beauv. var. nov.* typhoidea.

This variety was received from Sind only and is characterised as follows :—

Height $3\frac{1}{2}$ feet. *Leaves* about 18 inches long and $\frac{3}{4}$ inch broad. *Spikes* purple brown, cylindrical or slightly club-shaped, broad at apex, length 5 inches, breadth 1 inch, *bristles* slightly exceeding the spikelets. *Glume* III narrower and more acuminate than in any of the other varieties.

General remarks on Setaria italica and its varieties.

The result of my analysis of many samples under vernacular names is that the name *Chino* is applied in Sind to the variety which I have called *typhoidea ; Savri* is applied in Sind to S. italica *type ;* the Marathi names, *Rala*, *Kang* and *Bhadli* are given to all varieties indifferently ; *Kang* is the Gujarati term ; while *Navani* seems to be the correct name in Kanarese, although *Kang* is also used.

Sir George Watt and Mr. J. F. Duthie state that S. italica occurs wild in India on parts of the Himalayas. De Candolle, however, doubts whether it has been found truly wild anywhere. He asserts that the species existed before all cultivation, thousands of years ago, in China, Japan, and the Indian Archipelago. Its cultivation must have early spread towards the West since we know of Sanskrit names, but it does not seem to have been known in Syria, Arabia and Greece, and it is probably through Russia and Austria that it early arrived among the lake-dwellers of the Stone age in Switzerland.

Mr. Duthie says that "S. italica is both wild and cultivated in India and largely grown in other warm countries. In Northern India it is usually sown as a subordinate crop accompanying *Juar* (Andropogon Sorghum) or *Sawn* (Panicum frumentaceum). It is cultivated on the Himalayas at low elevations. Its abundant and nutritious foliage yields an excellent forage if cut

when in blossom." In Australia it is considered to be a good, fattening, pasture grass. In the United States, where it is known under the name of "Hungarian Grass" it is much valued. Professor Phares quoted by Dr. Vasey remarks, "if cut at the right stage the whole plant is a safe and very valuable forage."

Mr. Mollison says "the grain is very easily rubbed out from the head of grain. It varies in size and colour according to variety. The seed is oval, more pointed at one end than the other, smooth, shining. The more common colours are creamy white, dirty creamy white, yellow orange, light red brown. In one variety brownish black glumes enclose creamy white seeds. In the Bombay Presidency, the crop is annually becoming more popular and the area has considerably increased within recent years. It is a quick growing cereal and a suitable crop to grow after a period of famine or scarcity. It produces a good deal of grain and a fair amount of fodder in quick time. It thrives best in medium light soil and does better than other millets with deficient rainfall. The straw makes good fodder."

Professor Church, in his analysis of the grain, gives the Nutrient Ratio or Albuminoids to Starch 1 : 7·4 ; Percentage of Albuminoids 10·8 ; Nutrient value 91, and the following details:—

Composition of Husked (Italian) Millet.

	In 100 parts.	In 1 lb.
Water ...	... 10·2	1 oz. 277 grains.
Albuminoids ...	... 10·8	1 „ 318 „
Starch ...	... 73·4	12 „ 63 „
Oil ...	... 2·9	0 „ 203 „
Fibre ...	... 1·5	0 „ 105 „
Ash ...	... 1·2	0 „ 84 „

In Dalzell and Gibson's Bombay Flora, Supplement, page 98, the authors give the following species, which must all go under one or other variety of Setaria italica :—

"9. Panicum italicum, *Roxb. Fl. Ind. I., p.* 302, *Kangnee, Kora, Kang,* a small grain, cultivated in the Ghat districts ; spikes a little different from those of P. frumentaceum.

"11. P. pilosum, 'Badli,' Echinochloa hispidula. Is cultivated more inland than the former three species and distinguishable by the long hairy rough spikes clustering all round the rachis."

[Sir J. D. Hooker, in the Flora of British India, may have reduced this to Panicum crus-galli, *Linn. var.* frumentacea after examination of Dalzell and Gibson's original specimens, but the description points without doubt to a variety of S. italica, which is often known as *Bhadli* in the Deccan districts, while I have no record of that name being applied to P. crus-galli. The spikes of the latter (P. crus-galli) are not long hairy and they certainly do not cluster all round the rachis.]

"12. P.—(?) sp.—'Rale,' much less hairy than the last, probably only a variety. The grain is deemed very nutritious and is a favourite food in cases of exhaustion. This is most certainly the typical form of S. italica."

In a more recent paper by Dr. J. Walter Leather, entitled "Indian Food-grains and Fodders, their Chemical Composition" (published in the Agricultural Ledger No. 7 of 1903, Food-grains and Fodders) the author gives the following analyses of the Grains and Fodder of Setaria italica :—

	Moisture.	Oil.	Albuminoids.	Soluble carbo-hydrates.	Woody Fibre.	Soluble mineral matter.	Sand and Silica.	Total Nitrogen.	Albuminoid Nitrogen.
				GRAIN.					
"Rala," Poona	7·75	4·54	10·37	67·19	5·22	1·44	1·49	1·68	1·66
"Kangni," Panjab	10·11	4·96	10·50	67·81	6·29	1·74	2·59	1·75	1·68
"Swank," Panjab	10·25	4·33	10·62	65·37	6·18	2·25	1·00	2·07	1·70
"U. Rai-Soh," Hill Districts, Assam.	11·96	3·46	10·25	62·79	6·23	2·98	2·33	1·72	1·64
4 Samples, average	10·02	4·32	10·44	65·29	5·98	2·10	1·85	1·80	1·67
				GREEN FODDER.					
"Kangni," Panjab	76·79	·54	2·08	10·08	6·37	1·82	2·32	4·8	3·32
" Dry State ...	10·00	2·09	8·07	39·11	24·71	7·06	9·00	1·86	1·28

EXPLANATION OF PLATES.

I. Setaria glauca.

II. Setaria italica (type).

III. Setaria italica, *var.* barbata.

IV. Setaria italica, *var.* purpurea.

V. Setaria italica, *var.* typhoidea.

The letters and figures refer to identical parts in all :—

A. A spike with the uppermost leaf (*nat. size*).

B. A cluster of spikelets (*nat. size*).

C. A single spikelet (*enlarged*).

D. 1 = Gl. I ; 2 = Gl. II ; 3 = Gl. III and its *pale*. 4 = Gl. IV and its *pale*.
5 = Fertile flower (*all enlarged*).

PLATE I.

Setaria glauca

M.G.S.

PLATE II.

Setaria italica (type)

PLATE III.

Setaria italica, var. barbata

M.G.S.

PLATE IV.

Setaria italica, var. purpurea

M.G.S.

PLATE V.

Setaria italica, var. typhoidea

STUDIES IN INDIAN FIBRE PLANTS.

No. 2. ON SOME NEW VARIETIES OF *HIBISCUS CANNABINUS*, L. AND *HIBISCUS SABDARIFFA*, L.

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I. *HIBISCUS CANNABINUS*, L.

1. Introduction.

Hibiscus cannabinus, Deccan or ambari hemp, is perhaps the fibre plant in India most widely cultivated for local consumption. It does not appear to be grown to any great extent in other parts of the world.[1] This crop, owing to its distribution over the whole of India, is known under a very large number of vernacular names, e.g., *ambári*, *ambadi*, *pulu*, *mesta pát*, *dare kudrum*, *pátsan*, *sheria*, *gogu*, *puṇdi*, *sujjádo* and *sankukra*.

It is usually cultivated as a mixed or border crop except on the East coast of Madras and to some extent in the jute-growing Districts of Bengal where it is grown pure. In Madras[2] its cultivation is firmly established in the Vizagapatam and Guntur Districts where the area under this crop is about 60,000 acres or six-sevenths of the total acreage in the Presidency. A mill for spinning the fibre and manufacturing it into gunnies has been worked for some years

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1 Dodge, *Descriptive Catalogue of useful Fibre Plants of the World*, Washington, 1897, p. 192.

2 *Proceedings of the Board of Agriculture in India*, 1909, p. 55.

at Bimlipatam in the Vizagapatam District and another mill has recently been opened at Ellore in the Krishna District. Besides its use as a fibre crop the young leaves and shoots are sometimes eaten as a vegetable.[1] In Bombay and the Central Provinces it is grown to a considerable extent, usually as a mixed crop, while on the alluvium of the Indo-Gangetic plain in Bihár, the United Provinces and the Punjab it is commonly seen in the *kharíf* only on the borders of fields.

The first condition for the successful cultivation of this crop in the alluvium is a well-drained and well-cultivated soil. In the growth of this plant at Púsa during the past four years the effect of local waterlogging has been most marked. In such situations the plants remain stunted and usually die before forming flowers and seeds. The leaves are small and narrow and the root development is exceedingly poor. Want of aeration of the soil has a similar ill-effect to that of waterlogging. This is particularly noticeable at the end of the monsoon when crops which have done well up to this time often show signs of wilting. In such cases unless the soil is immediately cultivated the plants die off. On the other hand they immediately revive when the soil is aerated. Under favourable conditions and especially when grown on high-lying freely draining soils which have been stirred from time to time the crop is tall and vigorous and large crops of good fibre are obtained. It is possible that the extreme sensitiveness of this crop to local waterlogging and want of aeration in the alluvium is the reason why it is grown as a border plant on the edges of fields where the soil is slightly raised and better drained than the rest of the land. If the cultivation of this crop is ever taken up in the plains on a large scale for fibre purposes waterlogging must be prevented and the necessity of frequent cultivation, especially after the monsoon, must be insisted on. Except for these two points the cultivation is simple and the best results

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[1] Roxburgh, *Coromandel Plants*, Vol. II, p. 48.

are obtained if the crop is sown on the early monsoon showers of June.

The crop is harvested in Bihár in November when the first formed seeds are just ripe and while the upper portion of the plant is still in flower. There seems to be some difference of opinion as to the exact period when the strongest fibre is obtainable. Roxburgh[1] found that cord made from plants in flower broke at 115 lbs. while that from plants in fruit broke at 110 lbs. Watt,[2] on the other hand, states that "full-grown plants which have ripened their seed furnish stronger fibre than if cut while in flower." The plants are retted in water for ten days or more according to the temperature. At first, the bundles are placed vertically in water to soak the thick root ends only after which they are laid horizontally and completely immersed.

The fibre thus obtained is much more glossy and lighter in colour than *sann* but is harsher and the fibres adhere more closely to one another. The following description of the fibres is taken from Hanausek's *Microscopy of Technical Products*.

Gambo hemp.[3]

"The fibres are yellow-white to grey-yellow, slightly lustrous, somewhat lignified. On treatment of a cross-section with iodine and sulphuric acid, it is evident that the lignification is not uniform throughout. In many fibres the walls are yellow, with a rather brown outer lamella ; in others the inner layers of the walls are deep blue, only the outer lamella being yellow. Whole fibres treated in the same manner also show irregularities in colour. These differences may explain some of the contradictory statements of different authors. Wiesner[4] states that the bast cells on treatment with iodine and sulphuric acid swell and become

1 Roxburgh, l. c.

2 Watt, *The Commercial Products of India*, London, 1908, p. 630.

3 T. F. Hanausek, *Gambohanf. Realenzyklopadie d. ges. Pharm.*, 2. Aufl. 1905. 5, 511, v. Hohnel : *Mikroskopie der technisch verwendeten Faserstoffe*, Wien. 2. Aufl. 1905, 56, Matthews, *Textile Fibres*, New York, 2nd Ed., 1907, 303.

4 *Die Rohstoffe des Pflanzenreiches*, Leipzig, 2. Aufl. 1903, 2, 31.

indigo blue, even to the innermost layers, while v. Hohnel notes only a yellow coloration. v. Hohnel[1], however, employed dilute sulphuric acid, which does not give a blue coloration.

Microscopic structure. The technical fibres consist only of bast fibres. These are up to 6 mm. long, 14-16$_\mu$ (according to v. Hohnel mostly 21$_\mu$) broad, and are either blunt, sometimes with a very short lobe near the end, or else pointed, the walls at the ends being in both cases very strongly thickened. The lumen in one and the same fibre shows very great variation in diameter, in some parts it is broad, in other parts narrow, and in still other parts disappears entirely. Frequently it is alternately broad and narrow. In cross-section the fibres are seen to be closely united, and are either polygonal with sharp angles and straight sides or rounded polygonal with sharp angles and oval, the lumen in the first case being usually small, often a mere point, in the latter case large and oval. Cross-sections examined in water show a broad, distinct outer lamella, but concentric rings are evident only in some of the angular forms and in those but indistinctly.''

Most of the fibre produced in India is used locally, and is mainly employed in making the string and cord necessary for agricultural operations. Coarse sack cloth and canvas are made from it in some parts as well as fishing nets and paper. The export trade in this article is comparatively recent as Royle[2] in 1855 stated ''Though so generally cultivated, its fibre is hardly if at all known as a distinct article of commerce.'' It has since, however, been introduced into the English market under the name of Gambo hemp, fibre of the Roselle and jute of Madras. It also occurs as an admixture to *sann* and other Indian fibres. It is stated that some years ago this fibre was put on the English market under the name of Bimlipatam jute[3] and commanded a good price; £11 to £12-10 a ton. According to Watt[4] the demand for Bimlipatam jute is steadily increasing, the export value in

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1 *Mikroskopie der technisch verwendeten Faserstoffe*, Wien. 2. Aufl. 1905, 44.
2 Royle, *The fibrous plants of India*, 1855, p. 257.
3 *Agricultural Ledger*, 1903, No. 2.
4 Watt, l. c.

1903-04 being 2 lakhs of rupees. Wiesner[1] considers that the fibre, if more carefully prepared, might give a useful product and lays stress on the fineness of the fibres. The crop is an easy one to grow and is widely distributed in India so that if a good price could be obtained in London there is no reason why an export trade should not be maintained.

2. Pollination and natural cross-fertilization.

In 1906, five samples of seed of this crop were obtained from Madras by the Fibre Expert to the Government of Eastern Bengal and Assam. Three were named, *paddy gogu*, vegetable *gogu*, Ongole *gogu*, and two samples from Coconada were unnamed. These were handed to us for botanical examination and were sown in the botanical area at Púsa in July of that year. These five samples proved to be mixtures of several distinct varieties, some of them being so different as to suggest a mixture of species. Purple stemmed plants with entire leaves, green stemmed plants with similar leaves, and purple and green stemmed plants with divided leaves as well as other less distinctive forms were found. The same varieties occurred in all the plots and no great differences could be found between the plots as a whole. In 1907 two more samples of seed were sown, Bengal *patsan* and *desi patsan* from Lyallpur but no new forms were detected. The crop as grown in Bihár and in many parts of Northern India appears to be generally of one variety, a green stemmed type with green palmately divided leaves.

Seed (produced under bag and also from free-flowering plants) of all the forms identified was collected from several individuals. The seed of each plant was sown separately the following season. Some of the cultures thus obtained were uniform and resembled the parents in every respect, but from some of the unbagged seed the progeny was not uniform, for example, seed from an entire leaved plant gave both plants with entire and with divided leaves.

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[1] Wiesner, l. c.

Mixed cultures of this crop can often be detected in the seedling stage. It was found that great care was necessary in thinning to prevent the coolies and boys from removing all the seedlings which differed from the bulk of the culture. If left to themselves they invariably removed everything which differed from the bulk of the culture and so unconsciously rogued the plots. It was necessary to watch the thinning of the cultures personally and to point out which plants were to be removed.

Every year cultures obtained from single free-flowering plants were mixed and often contained individuals which differed from any of the types in cultivation at Púsa. In 1909, seed from a large number of aberrant plants found in these single plant cultures were collected and the seed of each plant was sown separately. In every case the progeny was mixed. On the other hand in 1910 no case of splitting was observed when seed of the types described in the present paper was obtained under bag and sown. Cross-fertilization in this species is therefore very common when the various forms are grown next to next and allowed to flower freely. A study of the methods of pollination in this crop shewed that the opportunities for cross-pollination by insects are very great.

The flowers of this species open in the early morning before daybreak and begin to close about midday. The closing of the flower is fairly rapid and before sunset the partially withered corollas are twisted up in the manner shown in Plate I. During the night still further twisting of the corolla takes place, giving rise to the cottage loaf shape of the withered flower shown opposite.

The method of pollination of the flowers of this species is of considerable interest and does not seem to have been previously studied in detail. When the flowers open, the stigmas are at the mouth of the staminal column and the anthers have not yet commenced to burst. Soon after daybreak, the stigmas still remain flush with the opening of the column. After this the turgidity of the filaments falls off and the burst anthers bend back towards the

PLATE I.

THE POLLINATION MECHANISM OF HIBISCUS CANNABINUS.

column. Simultaneously the styles elongate and carry the stigmas into the air beyond the opening of the column and at this stage pollen grains are rarely seen on the stigmas. Sometimes, however, the styles bend outwards and carry the stigmas on to the pollen, thus bringing about self-pollination. Frequently no pollen is seen on the stigmas when the flowers begin to close about midday. If closed flowers, however, are opened carefully it is found they are always well pollinated. Self-pollination is effected almost entirely by the closing of the corolla. The limb of the petal is thin, the claw very thick. The corolla closes by the falling towards the centre and twisting of the thin limbs. This brings the corolla in contact with the burst anthers and the completion of the closing of the flowers covers the stigmas with pollen.

It will be seen that the flowers are adapted both for cross and self-pollination. From the time the styles begin to carry the stigmas beyond the opening of the column to the closing of the flower crossing is possible. Self-pollination, however, may also occur during this period. A sufficient supply of seed is ensured by the very effective method of selfing when the flower closes.

The flowers of this species do not set seed under bag in the ordinary way unless artificially self-pollinated. This is due to the fact that the flowers do not close normally in the bag. The thin limbs of the corolla do not fall together and twist in the usual manner, possibly on account of the even humidity of the air both outside and within the closing corolla.

The production of a sufficient supply of selfed seed from a single plant in this crop is an exceedingly tedious operation. It has already been stated that the flowers do not set seed under bag in the ordinary way on account of the failure of the closing mechanism of the corolla under such conditions. The flower buds have to be bagged singly in the evening and selfed the following morning about 9 to 10 A.M. when the anthers are ready to burst the moment the bag is removed. Except when grown singly or at the edges of a plot this crop does not branch much. As the flowers usually open singly and are borne in acropetal succession on the main

stem only one flower can be selfed every day. After setting the bag is moved upwards above the young capsule and if care is taken a succession of selfed capsules can be obtained on the stem one above the other. The short peduncles, however, are exceedingly brittle and inelastic and if damaged the capsules drop.

In order to distinguish the selfed capsules from any free-flowering ones produced after the self-pollinating process is over it was necessary to adopt a special procedure. Labels tied on in the ordinary way just below each selfed capsule were unsatisfactory as they frequently worked loose and slipped down the smooth stem, especially when the plants drop their leaves as the ripening process proceeds. Each selfed capsule was indicated by passing a thread to which a small light card-board label was attached through the stem by means of a needle just at the insertion of the peduncle. At harvest time no difficulty was experienced in reaping the selfed capsules and in rejecting the free-flowering ones. In this way a great saving of time was possible and it was not necessary to visit the plants periodically to remove any subsequent flower buds and to readjust labels.

3. The varieties of H. cannabinus.

Mention has already been made of the fact that among the pure line cultures obtained from selfed seed several different varieties were found. In all, five varieties comprising eight agricultural types, have been isolated. These differ from one another in many particulars and a detailed description of each type with a coloured plate of one type of each of the five varieties is given below. As far as we have been able to ascertain in the literature at our disposal none of these types except the common form (Type 7) with divided leaves and green stems have been described previously. The main differences between the types may be seen from the following summary :—

1. Var. *simplex.*

Type 1. Stems purple; leaves entire with purple petioles. (Plate II.)

PLATE II.

Var. *simplex*. Var. *viridis*.

VARIETIES OF H. CANNABINUS WITH SIMPLE LEAVES.

PLATE III.

Var. *vulgaris*.   Var. *ruber*.   Var. *purpureus*.

VARIETIES OF H. CANNABINUS WITH DIVIDED LEAVES.

2. VAR. *viridis*.

Type 2. Stems green; leaves entire with green petioles. (Plate II.)

3. VAR. *ruber*.

Type 3. Stems red below, greenish above; leaves divided with green petioles. (Plate III.)

4. VAR. *purpureus*.

Stems purple; leaves divided with purple petioles.

Type 4. Late, stems very tall and slender; leaves with narrow lobes of a diffused purple colour; petals purplish. (Plate III.)

Type 5. Early; stems short and robust; leaves green with broad lobes.

5. VAR. *vulgaris*.

Stems green; leaves divided with green petioles.

Type 6. Plants very early.

Type 7. Plants late; seedlings with reddish stems. (Plate III.)

Type 8. Plants late; seedlings with green stems.

The following is the description of *H. cannabinus* as given by Hooker in the *Flora of British India.*

"*Hibiscus cannabinus*, L. DC. *Prodr.* i, 450; annual or perennial, prickly, stem glabrous, lower leaves entire, upper lobed, mid-nerve glandular beneath, peduncle very short, bracteoles 7-10 linear, shorter than the calyx, sepals grandular. *Cav. Diss.* iii, 148, t. 52. f. 1; Roxb. *Fl. Ind.* iii, 208; *Cor. Pl.* i, t. 190; *Wall. Cat.*, 1898; *W. & A. Prodr.* i, 50; *Thwaites Enum.* 26; *Dalz. & Gibs. Bombay Fl.* H. Wightianus, *Wall. Cat.* 2695 and 1898.

Generally cultivated; apparently wild East of the Northern Ghats. Distrib. *Cultivated in most tropical countries.*

Stem glabrous, prickly. *Lower leaves* cordate, upper deeply palmately lobed, lobes narrow, serrate; petiole prickly, lower much longer than the blade. *Stipules* linear, pointed. *Peduncles* axillary, very short. *Sepals* bristly, lanceolate, connate below the

middle, with a gland at the back of each. *Corolla* large, spreading, yellow with a crimson centre. *Capsule* globose, pointed, bristly. *Seeds* nearly glabrous. All parts agreeably acid. The stems furnish fibre. The specimen of *H. Wightianus* in Wallich's herbarium is imperfect, but it is doubtless referable to this species; its leaves are simple.''

This description refers to the green stemmed form with divided leaves so common in Northern India. This is the form always referred to in the literature published up to the present and is figured in Roxburgh's *Coromandel Plants.* In his concluding sentence Hooker mentions a form with simple leaves. This is the only allusion in the literature to the occurrence of distinct varieties in this species. It appeared to us almost incredible that such well-marked types as the purple stemmed form with entire leaves (Type 1) and the purple stemmed form with divided leaves (Type 4) should have escaped attention, considering that the value of *H. cannabinus* as a fibre plant is discussed and the plant described in all the modern and also in the older books dealing with Indian economic plants. A search was therefore made in the literature at our disposal and the collections in various herbaria were examined to see if the rarer forms of this species, which differ very much from the form described in the *Flora of British India,* had been recorded under other names. Through the courtesy of Major Gage, I.M.S., we were able to examine the specimens of the genus *Hibiscus* in the Calcutta Herbarium and also the valuable collection of coloured drawings. The Reporter on Economic Products to the Government of India kindly sent us the herbarium specimens of the genus in the India Museum, Calcutta, and all the information on the subject at his disposal. While on special duty in England during the current year (1910) we examined the collections of the Linnean Society of London.

Neither descriptions nor specimens of the new types could be found under any other species of *Hibiscus.* The only reference to aberrant forms found in the literature is the one quoted above from the *Flora of British India.* Herbarium specimens of a few

of the types are to be found in the collection at the Indian Museum but they are designated *H. cannabinus* with no comment, except in one case when there is a note on a specimen with a purple stem and divided leaves to the effect that "green and intermediate coloured plants are intermixed. In fact there is no distinction into two races."

It appeared at first probable that the specimen referred to by Hooker as *H. Wightianus* might prove to be either type 1 or type 2 and, through the kindness of Major Gage, herbarium specimens of the types isolated by us were despatched to Kew for comparison with this specimen. The following reply was received :—

H. 330-10 Royal Botanic Gardens,
Kew.

"The Director of the Royal Botanic Gardens, Kew, presents his compliments to Major A. T. Gage, I.M.S., and begs to inform him that the specimens of *Hibiscus* received are not identical with *H. Wightianus,* Wall. The leaves of Wallich's 2695 are much more coarsely and deeply serrate and their petioles are much shorter than those of the specimens received. The stem of *H. Wightianus,* it may be added, is whitish."

In 1910, while on special duty in England, we had the opportunity of examining Wallich's specimens at the Linnean Society. In addition to the information in the above letter it was observed that the epicalyx of *H. Wightianus* is of a very different form to that of any of the types isolated by us. It is much longer, rounder, more spreading and covered with hairs while all the Púsa types have short stiff glabrous epicalyces. It is evident, therefore, that types 1 and 2 are not referable to *H. Wightianus* which, indeed, appears to differ so materially from *H. cannabinus* as to deserve recognition as a separate species. Another specimen from the same collection, namely, Wall. No. 1898, which was referred by Masters to *H. Wightianus*, differs still more markedly in the form of its epicalyx, the lobes of which are expanded at the apex and

different from those of *H. cannabinus* & *H. Wightianus*. By the kind permission of Dr. Jackson we were enabled to have photographs made of both these specimens and these are reproduced in Plate IV. A comparison of these with the coloured plate of the Púsa types will make these differences clear.

The new forms isolated at Púsa must, therefore, be regarded as hitherto undescribed varieties of *H. cannabinus*. We consider it better to class them all as varieties and not to make any new species. In spite of the difference in the leaf form varieties 1 and 2 resemble the ordinary *H. cannabinus* so closely and cross so easily with it that it would seem inadvisable to separate them. The differences between types 6, 7, 8 and between types 4 and 5 are not of the nature of varietal differences and these forms have, therefore, been designated as agricultural types.

There are considerable differences between the eight agricultural types. Type 4 is too delicate for growth in the plains, while types 3, 6 and 7 are likely to be more useful for fibre than the rest. Type 7 is the common form of the plains and is fairly robust. Type 6 is very promising on account of its earliness and straight unbranched stems. It would be possible to harvest this crop in time for a succeeding *rabi* crop. Type 3 is the most vigorous of all. It produces very tall straight and stout stems and thrives well even under defective cultivation. It appears to be a very promising type for Northern India. Experiments are in progress at Púsa to compare the yield and quality of the most promising types when grown in pure culture, and if type 3 fulfils its early promise the introduction of this kind into cultivation would be a distinct improvement.

4. Description of the Types.

The main distinctions between the varieties have already been indicated, but there are in addition many interesting minor points of difference. The following description is common to all the eight types.

PLATE IV.

WALL. No. 1898.

WALL. No. 2695. H. WIGHTIANUS.

Annual, *leaves* midnerve glandular beneath, petiole prickly, long ; *stipules* linear, pointed ; *flowers* axillary, open for a few hours only ; *peduncles* axillary, very short ; *epicalyx* shorter than the calyx, stiff, consisting of 7-10 bracteoles connate below free above ; *calyx* connate below free above ; *sepals* bristly, lanceolate, with a gland at the back of each ; *corolla* large, spreading, thickened below, very thin above ; *capsule* globose, pointed, bristly ; *seeds* nearly glabrous.

Type 1. Plants early. *Stem* comparatively short, stout, prickly, purple, side branches stout, arising near the base and remaining parallel to the main stem. *Stipules* purple. *Leaves* subcordate, simple, occasionally slightly lobed; margin purple, occasionally some purple colour on the veins both on the upper and lower surface ; texture coarse ; petiole purple. *Peduncle* purple. *Epicalyx* green with some purple. *Sepals* green with a few purple spots ; apices green ; central gland green with a red spot. *Corolla* yellow with a crimson eye, some purple colour diffused over upper part of petal. *Seedlings* stem dark red ; petiole dark red ; cotyledonary leaves red above green below.

Type 2. Plants early. *Stem* comparatively short, stout, green, side branches stout, arising near the base and remaining parallel to the main stem. *Stipules* green. *Leaves* subcordate, simple, occasionally slightly lobed; margin red; lamina and veins green; texture coarse; petiole green. *Peduncle* green. *Epicalyx* green. *Sepals* green; central gland green. *Corolla* yellow with a crimson eye. *Seedlings* stem, petiole and cotyledonary leaves green.

The collection at the India Museum contains specimens of *H. cannabinus* with simple leaves from Kyaukse, and other places in Burma and also from Bezwada, Madras, but it is impossible to say whether they belong to type 1 or to type 2.

Type 3. Plants fairly early, very robust, setting much seed. *Stem* tall, stout, prickly, red except the upper 6 or 7 inches which remain green. *Stipules* green. *Leaves* palmately divided into 3-7 (usually 5) lobes, a few are simple and subcordate, the upper leaves lanceolate, green; margins red; petiole red. *Peduncle* green.

Epicalyx green. *Sepals* green with a few red spots. *Corolla* yellow with a crimson eye. *Seedlings* somewhat small, stem red; petiole red; cotyledonary leaves green.

Type 4. Plants late, delicate, setting few seeds. *Stems* very tall, slender, prickly, purple with spiry thin branches on the upper two-thirds. *Stipules* purple. *Leaves* generally palmately divided, with 3-7 (usually 5) narrow lobes, a few leaves simple and subcordate, the upper ones are occasionally lanceolate, dark green with much purple colour on the veins on the upper and lower surface; margin purple; texture thin; petiole purple, purple patches often appearing on the leaves. *Peduncle* purple. *Epicalyx*, upper surface purple, under surface partly purple. *Sepals* green with many purple patches; apices purple; central gland green with a red spot. *Corolla* yellow with a crimson eye, much purple colour diffused over the petals especially on the under surface. The closed bud appears purple. *Seedlings* slender; stem tall and dark red; cotyledonary leaves small and dark red.

Type 5. Plants intermediate in habit between types 1 and 4, setting a moderate amount of seed. *Stem* stout, prickly, purple. *Stipules* purple. *Leaves* palmately divided with 3-7 lobes (usually 5), broader and lighter green than in type 4; veins purple, margin purple; texture thin but thicker than in type 4; petiole purple. The leaves of this type are green in comparison with those of type 4. *Peduncle* green with some purple spots. *Epicalyx* green below purple above. *Sepals* green with a few purple spots; apices green; central gland green with a red spot. *Corolla* yellow with a crimson eye, with purple slightly diffused into the petals. *Seedlings* stem dark red; petiole dark red; cotyledonary leaves dark red.

Type 6. Plants very early, tall, almost unbranched. *Stem* smooth, green, occasionally slightly reddish. *Stipules* green. *Leaves* green, palmately divided with 3-7 narrow lobes (usually 5), a few simple and subcordate, upper leaves lanceolate; petiole green. *Peduncle* green. *Epicalyx* green. *Corolla* yellow with a crimson eye. *Seedlings* somewhat small; stem red; petiole red; cotyledonary leaves green.

Type 7. Habit intermediate between that of types 1 and 4, with less branching than in type 8. *Stem* smooth, stout, green. *Stipules* green. *Leaves* palmately divided with 3-7 (usually 5) lobes, a few simple and subcordate, the upper leaves lanceolate; margin red; leaves large and coarse in texture; petiole green. *Peduncle* green. *Epicalyx* green. *Sepals* green. *Corolla* yellow with a crimson eye. *Seedlings* large; stem reddish; cotyledonary leaves green.

Type 8. Plants later than type 7, habit intermediate between types 1 and 4. *Stem* smooth, stout, green. *Stipules* green. *Leaves* palmately divided with 3-7 (usually 5) broad lobes, a few simple and subcordate, the upper ones lanceolate, quite green; margin red; leaves large and coarse; petiole green. *Peduncle* green. *Epicalyx* green. *Sepals* green. *Corolla* yellow with a crimson eye. *Seedlings*, large; stem quite green; cotyledonary leaves green.

The main points of difference between the types are summed up in the following pargraphs:—

Habit. The types differ considerably in habit and consequently in their suitability for fibre purposes. The tendency to branch can best be observed on the edges of the plots where the plants have most room. The inside plants do not branch so much but if there is a tendency to throw out side shoots, this is not entirely lost even if the crop is grown thickly.

Types 1 and 2, with simple leaves, are similar in habit and are dwarf forms compared with the rest, with a strong tendency to throw out from the base numerous stout branches which grow parallel to the main stem. Type 5 is an intermediate form between the above and types 7 and 8 in which the tendency to branching is less marked and in which the thin, short side shoots arise not at the base but more evenly distributed up the stem. Types 3, 4 and 6 are similar straight tall forms in which the side shoots of the edge plants are thin and weak, and in which practically no branching takes place in the interior of the plots. As far as long clean stems are concerned the last three types are the most suitable for fibre purposes.

Vegetative vigour and duration of growth. In the vigour and growth period of the eight types there are wide differences which are of importance from the economic point of view.

Type 4 is exceedingly delicate, very sensitive to waterlogging and sets very few seeds even when grown under the most favourable conditions. The growth period is very long and flowers only appear after the other types have ripened some seed. Germination is slow and the seedlings are small, delicate and very slender. In spite of its tall unbranched stems these defects render this form useless as a fibre plant in the plains. Type 5 shows similar defects but to a lesser degree.

Type 6 is the earliest of all the types and ripens its seeds and begins to dry up while the others are flowering. This fact combined with its general vigour and tall unbranched habit render it of use as a rapidly ripening fibre plant for growth in the *kharif*.

Type 3 is the most promising form from the point of view of general vigour and its capacity to grow and to set seed under comparatively unfavourable conditions. It is a mid crop form and corresponds in growth period to type 7 the common form of the plains.

Leaves. The types can be divided into two classes, one (types 1 and 2) with entire leaves and the other with palmately divided foliage in which the number of lobes is generally five. Sometimes in types 1 and 2 a few leaves are met with which show a tendency to form lobes, but this is rare and the leaves as a rule are uniform. In the class with divided leaves the foliage is not uniform. The early formed leaves on the main stem and on the side shoots are often entire while the inflorescence leaves are first trilobed and finally lanceolate. The tendency to produce entire leaves is not equally great in all the types. In type 3 many entire leaves are found and a large number of the inflorescence leaves are lanceolate. On the other hand, type 4 does not usually show either simple or lanceolate leaves.

The width of the lobes also differs, those in type 4 are very narrow and those in type 7 are the broadest. The difference in

the width of the lobes of the leaves is an important distinction between types 4 and 5.

There are also differences in the texture of the leaves. Types 1, 2, 7 and 8 have coarse thick leaves with a puckered surface, while the leaves of type 4 are very thin and flat. Thin leaves are also met with in types 3 and 5.

Colour. The most striking differences in these types are colour differences. Not only is both red and purple found, but the localisation of the colour varies in a very interesting manner. From the natural crosses it appears that the red colour is dominant but is diluted in the F_1 generation. Many pink stemmed plants have been selected, all of which split into purple stemmed, green stemmed and pink stemmed plants in the next generation.

In type 4 the colour of the leaf is a dark bronze green with a tendency for purple patches to appear as the leaf gets old. The corolla shows a purple eye and much purple colour diffused on the petals especially at the back. The capsules also show a good deal of purple colour. In the whole plant the chlorophyll is masked and the general appearance is purple.

In type 5 the purple colouration is not so intense. The lobes of the leaves are entirely green and are broader than in type 4. The plants are shorter and more robust and the flowers earlier. The general appearance is that of a purple plant with green leaves. It will be seen in Plate III that the colour in type 3 is red rather than purple and that this colour only reaches to within 6 or 7 inches of the apex. This occurs both on the main stem and on the side branches.

Transverse sections show that the colour in the purple varieties is due to a crimson coloured cell sap which fills the entire epidermal layer and also the outer layers of the cortex. On mounting a section in water the cell sap of some of the epidermal cells readily diffuses out, turns blue and temporarily stains the collenchyma which lies beneath the chlorophyll-containing cortex. In type 3 the cells with coloured sap lie scattered in the outer layers of the

cortex with a few in the epidermis, but there is no continuous ring of two or three layers of coloured cells as in the purple types. The upper portion of the stem is quite green to the eye, but, nevertheless, contains scattered coloured cells. In types 6, 7 and 8 the stems which are quite green while growing vigorously, turn red as the plant gets old and when the fruits are ripe the stem may be as red as in type 3. Diseased or stunted specimens often show the same phenomenon. In transverse section the coloured cells are found to be scattered in the cortex as in type 3.

There is a tendency for coloured patches to appear on the blade as the leaves get old. These patches are purple in the purple stemmed kinds and red in the green and red stemmed types.

Seedling characters. In the summary on page 17 it will be seen that the distinction between types 7 and 8 rests on the colour of the seedlings only as the mature plants are indistinguishable. The seedlings of type 7 have reddish stems which turn green when the plants grow up while the seedlings of type 8 have green stems. This curious difference in the seedlings is constant appearing every year.

There are differences between the seedlings and young plants of the rest of the types with one exception, namely, in the seedlings of types 3, 6 and 7 where they are somewhat similar. Types 1 and 5 are alike in the very early stages when the cotyledonary leaves are red on the upper surface. In a short time type 5 shows divided leaves those of type 1 remaining simple throughout. The characteristics of type 4 appear in the seedling stage, the cotyledons are small and the young stems tall and slender. Types 2 and 8 have green seedlings which can soon be distinguished, the former forming simple leaves only, the latter divided foliage. The seedlings of the first generation of crosses between green and purple kinds are pink in colour.

The significance of these seedling differences as well as those which appear in the early stages of growth are of great importance and are dealt with in the next chapter.

5. A POSSIBLE EXTENSION OF THE METHOD OF PURE LINE CULTURES.

The constant differences observed between the seedlings of the types of *H. cannabinus* are of importance from two points of view. In the first place, they render the production of uniform fibre and pure seed a comparatively easy matter. In the second place, and this is by far the more important, they suggest a method by which the system of pure line cultures can be applied to some extent to the improvement of plants like cotton in which a certain amount of natural crossing takes place and in which it is essential to preserve uniformity in any improved type.

Uniformity is of great importance in fibre plants. Not only is it necessary for the crop to ripen at the same time so that it can be cut and retted at once but also the quality of the fibre must be uniform. Branched and straight growing forms growing together do not give fibre of even length while a mixture of different types even if they ripen together gives a product of uneven quality. The immediate loss of quality which results from growing an improved type with a small admixture of other forms is, however, small compared with the consequences of this proceeding which are only to be seen in succeeding crops. Not only do the constituents of the mixture appear in the next generations but also new forms arise from crossing between the original constituents. The quality of the fibre rapidly changes and is not constant from year to year. Any improvement observed in the first year is soon lost and the quality rapidly degenerates.

The differences between the seedlings and young plants of the various types of this crop enable a pure culture to be maintained without much trouble. Most of the stray plants which arise from accidental admixture can be detected by the differences they show in the seedling stage. Any which escape the first rogueing disclose themselves before the crop is a foot high. No difficulty would be experienced in carrying out this work in practice as the ordinary labour is easily trained to the work. Indeed the boys if

left to themselves in thinning this crop always remove any seedlings which differ from the bulk of the culture. A little extra care in attending to a plot raised for the purpose of growing seed for distribution to cultivators is all that is necessary to keep the culture pure and to prevent any natural crossing. The same care devoted to plots grown for fibre would ensure an absolutely uniform and even sample. If, as we suspect, it is found that type 3 is superior in vigour of growth, in the length and straightness of stem and also in yield of fibre to the other types, the maintenance of this form in a pure condition on a seed farm will not be a difficult matter. If, however, no care is taken to keep the seed-plots pure it will readily cross with other types and its qualities will be quickly lost.

The significance of the above results are of great importance from the point of view of the improvement of crops in India. In the case of crops which are usually self-fertilized an improved type can often be obtained by the selection of single plants and the comparison of their offspring in succeeding generations. The quality of any such improved strain can be readily maintained by keeping the seed-plots pure by rogueing and by starting the culture afresh from a single plant when necessary. In attempting to apply this method of improvement to crops which cross difficulties at once arise on account of the contamination of the cultures by vicinism before the preliminary work can be completed. If, however, it is possible, as in the case of *H. cannabinus*, to detect by their seedling or early vegetative characters most of the aberrant plants which arise, the difficulties due to crossing can be greatly reduced in the early part of the work and entirely obviated when one type only is being grown for seed distribution. All that is necessary is to study carefully the seedling and vegetative characters of the selected type and to remove systematically everything that appears in any way different from this. All this must be completed before the first flowers appear so as to prevent crossing with undesirable types.

It is possible that a study of the seedling characters will be of use on cotton seed farms where it is essential to maintain the quality

of any improved type and to prevent deterioration arising from indiscriminate crossing. Some rogueing might be done in certain cases in the seedling stage and the process could be continued and completed before the time of flowering. Cook[1] in a recent paper has drawn attention to the desirability of weeding out aberrant plants in cotton cultures grown for seed when the maintenance of the quality of any improved type is aimed at. For this purpose he suggests the vegetative characters of the desirable kind should be carefully studied and that any plants differing in habit should be removed as quickly as possible.

[1] Cook, *Cotton selection on the farm by the characters of the stalks, leaves & bolls*, Circular No. 66, Bureau of Plant Industry, Washington, D.C., August 1910.

II. *HIBISCUS SABDARIFFA*, L.

1. Introduction.

This plant, the red sorrel of the West Indies and the Rozelle or Rouselle (corruption of Oiselle) of Madras is cultivated in India for a variety of purposes. Almost every part of the plant can be utilized. The stems yielded a strong silky fibre known to commerce as "Rozelle Hemp." The fleshy calyces, which have a pleasant acid taste, and a very attractive red colour are extensively used in jellies, chutnies and preserves. In the West Indies a cooling drink is also prepared from them. The seeds are useful in medicine and the leaves are employed for salads and curries. Recently a further method of utilizing this plant has been suggested, namely, the extraction of a yellow dye from the petals. Material was sent to England by the Officiating Reporter on Economic Products to the Government of India and was examined by Professor A. G. Perkin, F.R.S., but the report was distinctly discouraging and it seems unlikely that any success will be obtained.[1]

This species is cultivated all over India (except in the hills) and in Ceylon. It is also extensively cultivated in Jamaica for fibre and in the West Indies generally for the calyx. In India the plant is known under the vernacular names of *mesta*, *patwa*, *lal ambari*, *kempu*. The cultivation is simple. *H. Sabdariffa* takes somewhat longer to come into flower than *H. cannabinus*, but is much less sensitive to waterlogging and to defective aeration. It is sown as a *kharif* crop and harvested in November or December. The height of the plants varies with the cultivation but may reach 10′. They branch profusely, the branches arising from the base and remaining parallel to the main stem which is not much stouter

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[1] *Agricultural Ledger*, No. 2, 1908.

than the branches. The stems and branches are supple but not very rigid, and the plant is lusty rather than erect and has a tendency to sprawl.

The stems are retted in the same manner as those of *H. cannabinus.* The fibres are silky and fine, but apparently not so strong as those of *H. cannabinus ;* the breaking strain of the latter is given by Wiesner[1] as 115 whereas that of *H. Sabdariffa* is only 89.

The following description of the fibre is taken from Dodge's *Descriptive Catalogue of the useful Fibre plants of the world.*

" A superb sample of this fibre was shown in the exhibit of British Guiana, W. C. E., 1893, which was accompanied by the stalks some 10 feet high, as straight and clean as jute stalks.

The fibre was equal, if not superior, to much of the jute which comes to this country. In my examination for award it was given the following rating: Length, 90 points; strength, 75 points; colour 80 points; average, 81·6."

Most of the descriptions and statements concerning *H. Sabdariffa* or Roselle refer to a plant with red stems and red calyces. In a few accounts mentioned is made of a variety with a white calyx but no description is given. It is sometimes said to be less acid than the red variety. No other forms are referred to in the literature. We have at Púsa isolated not only the red and the white varieties but two intermediate forms. These are partly red but in each the localization of the colour is different.

2. Pollination and natural cross-fertilization.

This species forms a striking contrast to *H. cannabinus* in the entire absence of natural cross-fertilization. Three varieties of Rozelle have been grown next to next at Púsa for four years and not a single instance of natural crossing has been observed. Seed from plants growing near the edges of the plots where the branches of two varieties interlaced was purposely chosen on two occasions

1 Wiesner l. c

for growing on in the following year but in all cases these plants bred absolutely true and the progeny was uniform.

The flowers open late in the morning and close at midday, remaining open for not more than three hours. The stigmas are throughout flush with the opening of the staminal column and do not grow into the air as in the case of *H. cannabinus*. The filaments are very short and the anthers burst round the opening of the column. Self-pollination is favoured by these arrangements and the completion of the process is brought about by the closing of the flower. (Plate V.) It will be seen that the differences in the pollination mechanism between this species and *H. cannabinus* are very slight but sufficient, in the present case, to prevent practically any cross-fertilization.

The peduncle of the flower is longer and much more supple than in *H. cannabinus*. Emasculation and artificial cross-fertilization present no difficulties and this species also sets seed fairly readily under bag.

3. Description of the varieties.

Four different forms in all have been isolated by us and these have bred true. As the differences are very distinct and are of a morphological nature rather than agricultural, we have formed the following four varieties :—

1. Var. *ruber*.

Stem and petiole entirely red, pulvinus red, calyx red, flowers on withering turn pink.

2. Var. *albus*.

Stem and petiole green, pulvinus green, calyx yellowish, flowers on withering remain yellow.

3. Var. *intermedius*.

Stem and petiole green with some red, pulvinus red, calyx yellowish green, flowers on withering remain yellow.

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4. Var. *Bhagalpuriensis*.

Stem and petiole green with some red, pulvinus green, calyx green with red splashes, slightly more obtuse and more twisted than in any of the other three varieties, flowers on withering turn pink.

With the exception of the slight difference in the form of the calyx in var. *Bhagalpuriensis* these four varieties are absolutely identical in all morphological and agricultural characters. They flower at the same time, grow to the same height and are equally robust. The only difference between them is one of colour.

The existence of two intermediate forms with small amounts of colour, quite differently located appears to indicate that the factors concerned in the occurrence of colour in this species are very numerous. Besides the main distinctions given in the synopsis of the varieties many smaller differences in the localisation occur. It is interesting to note that in the var. *intermedius* in which the flower resembles that of var. *ruber* in every respect, the corolla nevertheless remains yellow on withering instead of turning pink. In var. *Bhagalpuriensis* where there are differences in the colour of the pollen and of the eye the corolla turns pink like that of var. *ruber*. The tendency of the petal to change colour on fading would appear to be a definite character.

In the following table all the differences between the two intermediate varieties are given.

Var. *intermedius*.	Var. *Bhagalpuriensis*.
Stem. Green with two triangular red patches, one in the leaf axil and one below the petiole	Green with one triangular red patch in the axil of the leaf.
Pulvinus. Deep red.	Green
Calyx. Yellowish green with green apices, form as in vars. *ruber* and *albus*, gland on sepal yellowish green with a red spot.	Bright green with splashes of red, apices more twisted, shape more obtuse than in var. *ruber*, gland on sepal yellowish green without spot.
Corolla. Eye deep crimson, limb remains yellow on withering.	Eye slightly less crimson, limb turns pink on withering.
Pollen. Deep orange.	Orange-yellow.

The occurrence of var. *intermedius* is interesting. In 1906, a sample of seed of Rozelle was grown in the Botanical area at Púsa. It was noticed that this contained three or four white plants and these were harvested separately and sown next year. Among the plants so raised was *one* plant of var. *intermedius.* This plant bred true in the following and all succeeding years. It is difficult to account for the occurrence of this single intermediate plant among the white unless it be a mutation form. Roselle had never been grown before in the Botanical area and therefore admixture from seed lying in the ground was impossible. Another possibility, that this was the only surviving plant of an intermediate parent wrongly classed as white in the previous year is highly improbable. Each plant sets a great deal of seed, germination was good and no great mortality among the seedlings occurred. It is also unlikely that it is a natural cross breeding parthogenetically as emasculated flowers of this species have so far failed to set seed under bag. Unfortunately as the seed of the white plants was mixed before sowing, it is now impossible to state definitely that it is a mutation form. This variety has never been met with anywhere else and has so far not made its appearance again in cultures of var. *albus* at Púsa.

Var. *Bhagalpuriensis* was found in the neighbourhood of Bhagalpur. A number of plants, all similar, were found growing at the edge of a field on the Government Farm at Sabour. Seed of single individuals was collected and grown at Púsa this year, when the progeny was uniform and like the parent.

As it seems possible that cross-breeding experiments may give interesting information on the Mendelian factors regulating the localization of colour in this species, all these varieties have been crossed among themselves. They afford particularly valuable material for this work as they are all alike morphologically, ripen at the same time, are easily grown, set seed under bag and also as far as we have observed, do not reproduce parthenogenetically and do not cross when grown next to next. The first generation

PLATE VI.

Var. *albus.*

Var. *ruber.*

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of the cross between var. *ruber* and *albus* was grown this year and resembled the red parent in every respect.

It has already been stated that as regards agricultural characters there is no difference between the four varieties. For culinary purposes, however, the red one is decidedly the most useful both on account of its attractive colour and also because the calyx is less fibrous and harsh than in some of the varieties. The calyx of var. *Bhagalpuriensis* is scarcely edible on account of its tough stringy nature.

The four varieties are represented in Plates VI and VII and a detailed description of each is given below.

Shrub erect, annual. *Stem* glabrous, unarmed but with emergences at intervals, much branched with long branches arising near the base. *Stipules* generally simple and linear, sometimes bilobed. *Leaves* lobed, upper ones simple and lanceolate, with a pulvinus at the base of the blade, and a gland on the midrib of leaf; margin serrate; petiole often with a line of hairs on the upper surface. *Peduncle* solitary and axillary. *Epicalyx* united at the base and adnate to the calyx; bracteoles 8-12 linear. *Calyx* connate below free above; sepals 5-7, accrescent, fleshy, with a gland on the midnerve of each. *Corolla* yellow spreading, aestivation imbricate. *Capsules* ovoid, pointed, villous, shorter than the calyx. *Seeds* reniform, subglabrous.

VAR. *ruber*.

Stem dark red. *Stipules* dark red. *Leaves* green with some red colour on the lower surface of the veins, sometimes also on the upper surface; gland on the midrib colourless; petiole dark red except for a narrow strip on the under surface; pulvinus red. *Peduncle* red. *Epicalyx* red. *Sepals* red; central gland on midnerve greenish. *Corolla* yellow, with a deep crimson eye, turning a deep orange pink on withering. *Stamens* staminal tube red; pollen and anthers deep red. *Stigmas* red. *Seedlings* stem green with some red below the cotyledonary leaves; petiole red on the upper surface, green below; leaves green. (Plate VI.)

Var. *albus*.

Stem green. *Stipules* green. *Leaves* green, no red colour on the veins; pulvinus green; petiole green. *Peduncle* green. *Epicalyx* green. *Sepals* yellowish green; apices yellow when ripe. *Corolla* yellow with colourless eye. *Staminal* tube white showing up the yellow pollen. *Stigmas* white. *Seedlings* stem, petiole and cotyledonary leaves green. (Plate VI.)

Var. *intermedius*.

Stem green with some diffused reddish colour and with deep red triangular patches both in the axil of the leaves and also immediately below the petiole. *Stipules* green. *Leaves* green with some reddening on the upper surface of the veins; pulvinus red. *Peduncle* green. *Epicalyx* green. *Sepals* yellowish green; apices green when ripe, a red spot in the central gland on the midnerve. *Corolla* yellow with a deep or crimson eye, remaining yellow on withering. *Stamens* staminal tube red; pollen deep orange. *Stigmas* red. *Seedlings* indistinguishable from those of var. *ruber*. (Plate VII.)

Var. *Bhagalpuriensis*.

Stem green with some diffused red colour and a deep red triangular patch in the axil of the leaves. *Stipules* green. *Leaves* green, veins green; petiole green with a certain amount of diffused redness, pulvinus green. *Peduncle* green. *Epicalyx* green. *Sepals* bright green with splashes of red; central gland with a red spot. *Corolla* yellow with a crimson eye which is less deeply crimson than in var. *intermedius*, orange pink when faded. *Stamens* staminal tube red; pollen less deeply orange than in var. *ruber* and *intermedius*. *Stigmas* red. (Plate VII.)

PLATE VII.

Var. *Bhagalpuriensis.* Var. *intermedius.*

HIBISCUS SABDARIFFA. L.

NOTES ON THE INCIDENCE AND EFFECT OF STERILITY AND OF CROSS-FERTILISATION IN THE INDIAN COTTONS.

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THE subject of the economic significance of Natural crossing in India has been dealt with in a recent memoir* and it is, therefore, unnecessary to do more here than recapitulate in the briefest manner the reasons which necessitate, prior to any attempt at improvement in a crop, the determination of the extent of cross-fertilisation normally taking place.

The methods which can be adopted to procure improvement in a particular crop have been classified by Cook†, and in the choice of method the experimenter must be very largely guided by two considerations, the extent to which cross-fertilisation takes place under normal field conditions, and the degree of sterility which may result in plants subjected to artificial self-fertilisation carried out through a series of successive generations.

The ultimate aim of all scientific work on the agricultural crops is not only the production of a type suited to the particular conditions under which it will be grown and having a produce improved either in quality or quantity, but such production on a

* Memoirs, Dept. of Agr. in India, III, No. 6.

† U. S. Dept. of Agr., Bur. of Plant Industry, Bull. 146.

sufficiently large scale to admit of wide distribution. The work of improvement, therefore, falls into two sections—the production of such an improved type, or types, in a state of purity and the multiplication of these types when established, until a stage is reached when distribution may be attempted. On the extent to which natural cross-fertilisation is found to occur, will depend the precautionary measures which must be adopted to prevent a gradual deterioration of the crop after distribution has been commenced.

In the first stage the number of individuals handled will be limited, and it is possible to adopt artificial methods, by protection of the individual flowers or even of the whole plant, to prevent access to the flowers of foreign pollen of unknown origin. In this stage, if natural crossing is shown to occur, the determination of the limits to which continued self-fertilisation can be carried is of an importance greater than the determination of the extent of such crossing, for on this will depend the methods to be adopted in the isolation of improved types. In the second stage the numbers become too great for such artificial protection. The extent to which crossing takes place, then assumes a position of major importance, and, inasmuch as crossing between individuals of any particular type has no harmful influence, the determination of the conditions which render such crossing impossible is especially desirable.

That it is possible to determine with any mathematical precision the extent of cross-fertilisation taking place under certain conditions is hardly to be expected. The labour involved in attempting even a few such determinations would be considerable nor would it be safe to generalise from these, even when obtained, for in this particular it is quite possible that two similar types, or even individuals, might differ widely. For practical purposes a general idea of the extent of cross-fertilisation and the degree of sterility induced by repeated self-fertilisation is sufficient to indicate the methods and precautions it is necessary to adopt. The following observations on the Indian cottons are not, therefore, the outcome of a carefully planned series of experiments but rather

the collection of such observations as have a bearing on this subject, made during the course of a series of experiments having as their object the production of an improved cotton suited to the conditions of the United Provinces. As has been stated, they deal with two distinct phenomena, the occurrence of sterility, chiefly as the result of repeated self-fertilisation, and the frequency of crossing in nature, which two phenomena require separate treatment.

Sterility as the result of repeated self-fertilisation.

It is a matter of common knowledge that the extent of cross-fertilisation occurring in different plants in nature is most divergent. At one end of the series lie the diœcious species, in which self-fertilisation is impossible and from which, through the various forms in which, by protandry, protogyny, and the various adaptations, such as dimorphy, self-fertilisation is injurious, it is possible to pass to the other extreme, represented by plants with cleistogamic flowers, where self-fertilisation is the rule. The facts first collected by Muller* and Darwin† and more recently by Knuth‡ are so well known that it is hardly necessary to make further reference to this general aspect of the subject. It is sufficient to note that the cotton flower exhibits none of those adaptations which would indicate that it is normally either cross, or self-fertilised. There is, therefore, no *a priori* reason for anticipating any marked degree of self-sterility, indication of which can only be obtained from direct observation. Difficulty here arises through the absence of any method for directly measuring the degree of self-sterility, for such sterility may take various forms. Thus the fruit of flowers fertilised by their own pollen may fail to set or, having set, may undergo partial development only and fail to ripen. They may, on the other hand, produce seed which, when sown, gives rise to plants which are completely, or partially, ste-

* The Fertilisation of Flowers, 1873.

† The Effects of Cross and Self-fertilisation, 1876.

‡ Hand-book of Flower Pollination.

rile or which exhibit a lack of vegetative vigour. The subject, therefore, may be best handled by tracing the progeny of individual plants through a series of generations.

Observations on the incidence of sterility.

Type 3.* *G. arboreum*, L. The *Nurma* cotton of Northern India. In 1906 three plants of this type were grown and from these seed was obtained by the simple process of bagging the flowers. Of seventeen flowers so bagged eight set and gave seed. Of the plants raised from this seed in 1907, twenty flowers were similarly bagged but of these three only set. Later in the season, therefore, a further series of six flowers, in which cross-fertilisation from sister plants was effected, was bagged and of these two set. Mainly owing to the fact that *Nurma* cotton is readily obtained in a state of purity as the result of its growth being confined to the neighbourhood of temples and at a distance from the ordinary field cotton, and also to the fact that it is a perennial and can be rattooned, no further attempt has been made to grow this type from seed derived from self-fertilised flowers. The numbers are small but, as far as they go, show a marked diminution in fertility as measured by the percentage of fruits which set in the second generation.

Type 9. A form of *G. neglectum*, Tod., with white flower and a leaf-factor >3. A single plant culture of this type has been maintained since 1906. The original plant was then chosen on account of its prolific habit, the weight of bolls necessitating the use of artificial support. In this year fourteen flowers were protected and seed was obtained from seven of these. Of the offspring twenty-one flowers were similarly protected in the following year and of these nine only set. In 1908 some sixty plants were raised from the seed so obtained and of ten flowers protected not one set. In this case the carpels of the protected flowers did

* For the numbers here used to denote the types *cf.* Leake, Jour, of Genetics, I, pt. 3 (1911), and appendix to this note.

not undergo even the partial development that so frequently takes place, but the flower fell immediately and *in toto* from the base of the peduncle. An examination of the flowers of this generation disclosed a condition of almost complete sterility of the stamens which were white and shrivelled and rarely liberated pollen. Seven flowers were subsequently fertilised with the pollen gathered from sister plants and of these seven three set and ripened fruit. No detailed note has been kept of the subsequent (1909) generation but thirty-two flowers were protected and from these one hundred and twenty-three seeds (representing some fifteen bolls) were obtained. The sterile condition of the anthers, though present, was not such a marked feature of this generation. In 1910 a series consisting of forty plants was covered by a single net and has yielded seven and a half oz. seed.

In this case continued self-fertilisation appears to have brought about a marked degree of sterility which is, further, associated with the abortion, or incomplete development, of the stamens; also fertility has to some degree been restored by crossing between sister plants, but this restoration is partial only and the plants now representing this type exhibit none of that fertility which characterised the original plant first selected in 1906.

Type 6. A form of *G. neglectum*, Tod., with white flower and a leaf-factor $<$ 2. Two single plant cultures of this type have been under continuous cultivation since 1906. Of the original plants ten and twenty flowers were protected and from these six and eleven bolls respectively set. In 1907 eleven and ten fruits set from twenty-two and twenty flowers similarly protected. In 1908 the sterile condition of the anthers above noted as occurring in Type 9 made its appearance but was less defined in the first, than in the second, culture. In the latter the condition was as marked as in Type 9. In the former culture, therefore, flowers, eighteen in number, were protected and of these nine set, while in the latter a single flower only was protected and immediately fell. In this case sixteen flowers were fertilised with pollen from sister plants

and, as a result, nine fruits were obtained. Of 1909 full details are again lacking, but from fifty-four flowers of the first culture bagged ninety-one seeds (representing some eleven bolls) only were obtained, while of the second culture, in which crossing had taken place during the previous year, ten protected bolls gave sixty-nine seeds (representing some eight bolls). In both cultures in this year a further series of fertilisations was carried out in which flowers were fertilised by hand with (1) the pollen of a second flower of the same plant, or (2) the pollen of a sister plant.

In the former culture ten and nine fruits set out of twelve and thirteen flowers respectively, while in the latter three fruits set out of the seven flowers fertilised with pollen of the same plant, while all (three) set when pollen of a different plant was used. In 1910 the combined offspring of the second culture numbering forty-five plants have been protected by a single net and given eleven and three quarters oz. seed.

In this type, though both cultures exhibit the phenomenon of abortion to some extent, there appear indications of the existence of an individual difference in the degree of sterility induced by self-fertilisation. How far self-sterility in the cottons is a function of the individual can, however, only be determined by a definite series of experiments designed to elucidate the particular point. Sufficient has here been noted for the present purpose which is to show that it occurs to such an extent that it cannot be ignored if pure races are to be raised from single plant cultures without a loss of fertility.

These results are collated in Table I.

Other forms of sterility.

So far sterility has only been considered in its relation to pure types and there remains the case of the offspring of a cross. This forms a subject of considerable difficulty since, superimposed upon the sterility above dealt with, there may also exist that which arises as the result of specific or racial diversity. It is well known that the power to effect cross-fertilisation is strictly limited, that

while such fertilisation is readily effected between certain plants and will give rise to fertile progeny, in other cases it is totally unproductive. Between these extremes lie those cases in which offspring is produced but in which such offspring is wholly or partially sterile.

Observations as to this latter form of sterility are not numerous. As far as they go, however, these tend to show that the Indian forms of cotton constitute a fairly definite group, the members of which show complete sterility when crossed with other forms of Gossypia. Gammie* records failure in his attempts to cross *G. hirsutum*, Mill., by the Indian cottons and the authors have similarly been met by a like failure. Among the Indian cottons, however, there appears to exist considerable divergence in the degree of fertility when they are crossed *inter se*. In some cases no diminution of fertility results, while in others various degrees of sterility are developed. As examples of the former case may be cited all crosses between Types 5-9 (*G. neglectum*, Tod., and *G. roseum*, Tod.) ; between Type 3 (*G. arboreum*, Linn.) and Type 4 (*G. indicum*, Lamk.), Types 5-9, Type 10 (*G. sanguineum*, Hassk.) and Type 11 (*G. cernum*, Tod.) and also between Type 4 and Types 5-9. In all these cases crosses have been effected and fully fertile offspring raised. Crosses have also been made between Type 3 and Type 1 (*G. obtusifolium* Roxb.) and Type 2 (*G. herbaceum*, Linn.), and these offspring are apparently fully fertile. Owing, however, to the late flowering habit of these types considerable difficulty attaches to the cultivation of these crosses in Northern India and they were discarded after the F_2 generation.

Crosses between Type 2 and the sympodial forms, of which Types 4, 5 and 9 were selected for the purpose, showed a considerable degree of sterility. This is indicated by a comparison of the figures given in Table II. In the second generation of the cross between Types 2 and 4 the percentage of bolls which set was reduced to less than 11 and the plants of this generation set practically no

* The Indian Cottons, 1905.

seed. For this reason Type 2 has not been used in the experiments conducted with the object of raising races of improved cotton suitable to the United Provinces.

One further type of cotton, *G. Stocksii*, M. Mast., is found in India and has formed the basis of some experiment. Seed of this type was obtained from the wild plants found on the limestone hills around Karachi. Both *G. arboreum* and *G. herbaceum* have been crossed with this plant and in both cases seed was obtained. This seed germinated and gave rise to plants which have been grown for three seasons. They remained diminutive, however, and have died without producing any flowers, though the parent plants have flowered freely and subsequent generations have been raised from their seed. From this condition of complete sterility in the F_1 generation it is but a short step to those cases in which attempts to produce a cross have resulted in complete failure.

G. Stocksii, though found wild in India, differs in a remarkable degree from the other members of the Asiatic (Indian) group of Cottons (subsectio Indica) as defined by Todaro.* By Watt† it is placed in a different section of the genus and the correctness of its inclusion in the Genus Gossypium even has been called in question.‡ In this connection it is of some interest to find that, as far as experiments have been made, this plant forms the single instance of a cross between a member of the Asiatic series and other forms of cottons being produced.

The determination of the degree of sterility which may arise in the progeny of crosses such as have been considered above is a still more complex matter. Numerous cultures, involving several thousand individuals, have been carried by successive selfing as far as the F_4 generation. Certain of the plants of this generation display a very marked fertility and undiminished vigour. Others, on the other hand, appear to be nearly sterile though a case of complete sterility has not been observed. The cause of this divergence

* Osser. sui Cotoni, 1863.

† Wild and Cultivated Cottons of the World.

‡ Watt l. c. p. 56.

between plants of similar parentage remains obscure, and it has been found impossible to predict its occurrence in any particular plant or group of plants, and it appears to be a phenomenon quite distinct from the two forms of sterility above dealt with. The solution of the causes leading up to this fortuitous sterility is a matter which has a considerable practical bearing on the raising of improved races. That there lies here a field for cytological work* appears undoubted but hitherto the opportunity for conducting such work with the material to hand has been lacking.

The frequency of cross-fertilisation in the field.

(a) *The structure of the flower.*

The transference of pollen from one flower to another is, in general, effected by one of the two agencies, wind or insects and the flower is, further, frequently adapted to secure the services of a particular agent. Considered from this aspect the cotton flower shows but little adaptation. The petals are as a rule conspicuous and expand widely, and the pollen grains are large and round and covered with short papillæ. Nectaries occur at the base of the petals and the honey secreted by them accumulates outside the petals in the cup formed by the gamosepalous calyx and access to this honey is only obtained through the narrow slit-like passages between the five petals. The above structural peculiarities are such as are commonly associated with the visits of insects, and there is little doubt that whatever cross-fertilisation takes place is the result of such visits. On the other hand, the rupture of the anthers and consequent liberation of pollen synchronise very closely with the maturation of the stigma. During the cotton season the petals expand about 8 A.M. and within thirty minutes of this expansion the pollen is liberated and the stigma has become receptive. The pollen is at first sticky but soon becomes dry and powdery and falls on the slightest agitation of the flower. Though the position of the flower is by no means constant it is, perhaps, most commonly horizontal or pendent. The

* Cannon, Bull. Torrey Bot. Club, XXX, 1903.

flower, therefore, undoubtedly becomes self-fertilised within a very short period after the pollen is liberated. Moreover, the flower is ephemeral and the growth of the pollen tube is consequently rapid. Cross-fertilisation, therefore, is only likely to occur if foreign pollen reaches the stigma within the very limited period which elapses between the opening of the flower and the act of self-fertilisation. The brevity of this period suggests that cross-fertilisation will not be so common as the structural consideration would indicate.

(*b*) *The condition of the cotton crop.*

Indirect evidence as to the occurrence of cross-fertilisation is to be found in the condition of the cotton crop as usually cultivated. In Northern India the only types which are to any extent cultivated on a considerable scale are those falling under the designation of *G. neglectum* and *G. roseum* of Todaro and, in the Eastern districts of the United Provinces and Bengal, the types which have been grouped under *G. intermedium*, Tod. In both cases the field crop includes a most diverse assemblage of forms which defy classification until single plant cultures are grown under conditions which exclude cross-fertilisation. It is then seen that the apparently wide diversity of form resolves itself into a comparatively few types with which are mingled numerous intermediate forms which, when subjected to such rigid experiment, are found to be impure. The cause of the original mixing of types is, and will, no doubt, remain obscure, but the general occurrence of such impure forms must constitute a strong argument for the occurrence of cross-fertilisation.

For other parts of India, and especially the Deccan, Fletcher* has shown that the crop consists of a large mixture of types. In a few cases only, those of Broach (Type 2) and Dharwar Saw-ginned cotton (a form of *G. hirsutum*), is the crop pure. In the former case purity is maintained by the different flowering period of the crop while the latter form, as has been stated, does not cross with the Indian Cottons. Here the original cause of the mixing of types is no doubt in large measure due to the economic conditions mentioned;

* Agl. Journal of India, 1, 1906, p. 470.

but it is a significant fact that the only types grown pure are those whose natural habit helps to preclude the occurrence of cross-fertilisation.

(c) *Previous observations on the subject.*

From time to time the most divergent views on the extent to which cross-fertilisation takes place in the field have been advanced. At one extreme lie the views of Gammie who records* a series of observations which led him to conclude that "Indian Cottons are normally self-fertilised." At the other Cook† considers that it occurs with a frequency that might render it possible to produce on a commercial scale F_1 crosses by the simple process of growing the two kinds it is desired to cross in alternate lines. The crop raised from the seed so obtained will contain so many crosses that the pure parents may be rogued out without excessive thinning of the crop. It will be noted that these extreme opinions are based on observation of very different types growing in very distant localities. There is, therefore, no inherent difficulty in believing that both opinions may be correct for the particular types and for the particular area in which the observations were made. The structural similarity of the flower in all the types is, however, very great and on *a priori* grounds, therefore, it would seem probable that such differences as occur would be slight. It has been shown above that such crossing as takes place is caused by insect visitors and any divergence found in the amount which occurs is to be sought, therefore, not in the structural peculiarity of the flower but in the climatic conditions which obtain when the cotton plant is in flower and which directly affect the abundance or paucity of insect life.

Of the expressed views which lie between these two extremes those which are the result of observations made in India on the Indian cottons are most germane to the present question and may be dealt with first. It is impossible here to detail all the earlier observations on the subject. Reference to these is to be found in Watt's

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* The Indian Cottons, 1905.

† U. S. Dept. of Agr. Bureau Plant Industry Bull, 147.

article on Gossypium.* From their consideration as well as from the results of much personal observation, he has formed the opinion, expressed repeatedly throughout the article, that hybridisation has played a large part in the history of the cotton plant of India and even that many of the widely cultivated forms owe their origin to this process. Later, in a more recent work,† he expresses the same view.

Middleton has subjected the Indian cottons to a detailed examination covering a number of years. In the record of his results‡ he gives no definite expression of opinion on the extent of cross-fertilisation, but it is clear that he believes it to occur with a frequency which makes the origin of many cultivated races by this means possible. Thus of the Nadam cotton of Madras he writes, " I suppose Nadam to be " a hybrid with a strong strain of *G. arboreum*, the other parent being *G. herbaceum* or *G. indicum*," and the possibility of an origin of numerous other cultivated races by similar means is indicated.

Fyson,§ as a result of a series of experiments, was led to believe that a certain amount of natural crossing occurs. Thus he found the white-flowered parents from a cross between white-and yellow-flowered forms gave a few yellow-flowered offspring (two cases of forty-three observed). The occurrence of these he attributes to vicinism.

Burkill‖ has approached the subject from a different standpoint, having collected observations on the insects visiting the cotton flower. In the earlier note are recorded observations from Behar and in the later those made in Berar and Central India. He sums up the observations made in the former case by saying " It seems, " then, that insects such as I observed visiting the flowers in Behar " do produce an effect ; but it is an extremely small one indeed— " merely a hybrid plant here and a hybrid plant there."

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* Dict. of the Economic Products of India, esp. p. 39-42.

† The wild and cultivated cottons of the world, 1907, see esp. p. 90.

‡ Agricultural Ledger II, 1895, No. 8.

§ Memoirs of the Dept. of Agr. in India, Bot. Series II, 1908, No. 6.

‖ Jour. As. Soc. Bengal III, 1907, p. 517 and VI, 1910, p. 101.

A number of observations of a series of Indian types growing at the Royal Botanical Garden, Palermo, has also been made by Todaro.* As this work is not readily accessible a translation of his remarks may here be given.

" *G. herbaceum* Linn. in this cultivation of 1877 preserved " its character unchanged, as in all preceding years.

" In the different qualities of *G. wightianum* sown this year in " greater proportions, important phenomena were to be seen, which " show that this Indian species crosses very easily with the other " species proper to the Old World ; for it is sometimes crossed " with our *G. neglectum* and sometimes with *G. herbaceum var. micro-* " *carpum*, its hybrids assuming intermediate forms which link one " to the other ; but on repeating the culture of these hybrids, " which are all fertile, we get plants nearer to the types, and " in the second year some exhibit all the specific characters either " of *G. wightianum* or of *G. neglectum*, while cultivated separately " and at a great distance apart, they preserve their characters " intact.

" *G. herbaceum var. microcarpum* can fertilise *G. wightianum* " and *G. neglectum*, but it is never fertilised by them ; like the species, " however, the seeds of the hybrid constantly reproduce the same " plant. When *G. herbaceum* is repeatedly grown in poor ground " without irrigation, the capsules and leaves become smaller, the " plant is less branched, but the size of the flower and the shape " and divisions of the bracts do not vary ; this is not the case " with *G. wightianum* which is as easily fertilized by *G. neglectum* " as by *G. herbaceum var. microcarpum ;* the colour and size of the " flower do not change, nor does the capsule acquire the dimen- " sions of those of *G. herbaceum ;* and we never find in its bracts " the incisions and other characters which distinguish the species " with which it has been crossed.

" In these hybrids it is nearly always *G. wightianum* which " fertilizes *G. neglectum ;* the plants obtained resemble *G.* " *wightianum* in the characters of their leaves ; and in the second

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* Rev, Cult, dei cotoni, p. 48, 1878.

"generation, as well as more rarely in the first, there is a marked "reversion to *G. neglectum;* while a reversion to a pure "*wightianum* happens less frequently.

"Here it happens that in the large plantations of India there "exist intermediate forms which have made the English botanists, "who consider these hybrid forms simply as varieties of one "species, believe that between *G. arboreum* Linn. and *G. herbaceum* "there are so many links that they must constitute a single "species.

"The species cultivated in the Old World have no agricultural "importance; their capsules are always small, the wool is short and "rather coarse compared with that of the American kinds, and "cultivation has hitherto been unable to increase the dimensions of "their capsules, or to improve the cotton."

The occurrence of cross-fertilisation of cotton outside India has also been frequently noted. In America the belief in its occurrence though of limited extent, appears to be very general.

The opinions of several workers in America are recorded by Middleton.* Webber† states that "In several instances varieties "have been grown in single rows with other varieties all round "them of such a kind that crossing, where it occurred, could be "easily detected in the progeny. Plants grown from seed matured "under such circumstances show but few crosses, indicating "that the majority must have been self-fertilised. Judging from "the observations thus far made, it would seem that ordinarily "only 5-10 per cent. of the seeds are normally cross fecundated."

The same author has also dealt with the effects of the occurrence of such cross-fertilisation in its bearing on the methods of selection.‡

The work of Cook has already been referred to (p. 11). His observations on certain Egyptian cottons grown in America point to the hybrid nature of some of the plants.§

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* Loc. cit., p. 24.

† U. S. Dept. of Agr. Year-book, 1902, p. 370.

‡ U. S. Dept. of Agr. Year-book, 1898, p. 364 et seq.

§ U. S. Dept. of Agr., Bur. of Plant Ind., Bull. 156, p. 20.

In Egypt Foaden* has drawn attention to the difficulty attaching to the complete eradication of the inferior Hindi cotton by any method of roguing. Balls† has noted the mixed nature of the crop and, from his observations, calculates‡ that "all the kinds of cotton which I have grown in Egypt are liable to *at least* five per cent. of cross-fertilisation per annum.§

Observations on the incidence and extent of Cross-fertilization in the field.

This subject has been dealt with very briefly in an earlier note‖ in which a few early observations on the occurrence of natural cross-fertilisation in Northern India were described. Two instances alone were described in any detail and since these have formed the subject of further experiment, they may be treated more fully here.

In the first case, a single plant of a number belonging to the forms included under the term *G. neglectum* Tod., which were self-fertilised, gave offspring whose several leaf factors ranged over the entire scale while the offspring of the remainder were pure to this character. Eleven of the offspring of this plant, having leaf factors of different values, were again self-fertilised and in the subsequent generation it was found that those plants having a factor < 2 or > 3 bred pure, while the intermediate forms gave rise to a series of plants with leaf-factors of most divergent values. The results are given in Table III, section (*a*). If this is compared with section (*b*) of that table, which gives the results obtained from a cross purposely effected between two types known to be pure, the similarity will strongly suggest that the plant in question was the result of a cross between a broad lobed, and a narrow lobed,

* Year-book Khed. Agr. Socy., 1905.

† Year-book Khed. Agr. Socy., 1906.

‡ Jour. Agr. Sci. II, 1908, p. 353.

§ For further reference to this subject, see also Aliotta, Riv. Crit. del Genere Gossypium. Unfortunately opportunity for consulting this work has hitherto been wanting.

‖ Jour, As. Socy. Bengal IV, 1908, p. 13.

parent, though no indication of the remoteness of that cross is obtainable.

The second case is that of two plants raised from a packet of seed supplied as pure Nurma (*G. arboreum* Linn.). These differed from the type in being more vigorous, in having an intermediate leaf factor and the red colour of the plant slightly developed (as far as the veins). From one of these plants seed was raised and thirty plants were obtained. These thirty plants were classified into three groups.

(*a*)	Foliage and flower deep red	9
(*b*)	Foliage with red to veins, flower red on yellow ..	13
(*c*)	Foliage green, flower yellow	8

Of these groups four, eight and three plants, respectively, were self-fertilised and a subsequent generation raised from the seed so obtained. They may be considered separately.

(*a*) From the four plants of this group seventy-one were raised and were found to be pure as regards the character under consideration and in this respect they appeared typical of the type *G. arboreum*.

(*b*) Of the eight plants six gave the three forms (*a*), (*b*) and (*c*) only, in number thirty-five, sixty-four and fifty-five respectively; one of the remainder gave in addition offspring with the flowers red on white, while the last gave yet another additional form with white flowers. The numbers for these two plants are given below :—

			(1)	(2)
(1) Foliage full red	...	flower full red	...	3
(2) Foliage with colour to veins	...	flower red on yellow	10	10
(3) Foliage full red	...	flower pink	4	4
(4) Foliage with colour to veins	...	flower pink	5	
(5) Foliage green	...	flower yellow	8	6
(6) Foliage green	...	flower white	...	1

(*c*) Of the three plants with yellow flowers two have given thirty-seven offspring with yellow flowers only, while the third has given thirty-nine plants with yellow, and nine with white flowers.

Of the plants thus obtained in the series given under (*b*) a subsequent generation has been raised from the three with the foliage

bearing the red colour in the veins and pink flowers and from the single plant with a white flower. All the three former have given the two forms with pink flowers and also white-flowered plants, while the white-flowered plant has given whites only. The similarity between the behaviour of this series and that of the cross between Type 3 and Type 9 (red-flowered *G. arboreum* and a white-flowered *G. neglectum*) is so striking that it is impossible to avoid the conclusion that the original plant was derived from a cross between two plants having similar characters. It is needless to follow this series through the details of the leaf factor. That of the original plant was intermediate and the subsequent generations have split up in a manner similar in every respect to the case noted above. From its occurrence in a packet of seed of *G. arboreum*, it is probable that this plant was a first cross and it may safely be concluded that one parent was *G. arboreum* while the other must have been a white-flowered plant with leaf factor $<$ 2—probably a plant of Type 6.

It is unnecessary to enter in detail into each of the numerous cases of impurity which have been observed to arise in like manner in cultures raised from the seed of naturally fertilised fruits. In the few cases in which they have been investigated they have been proved by the character of their progeny to be the result of cross-fertilisation. For the present purpose it will be sufficient to describe the three series of observations which most clearly illustrate the point.

(1) Type 2 (*G. herbaceum, Linn.*) has been grown for a series of years; during the first two seasons only seed from protected flowers was sown and the culture so produced proved to be pure. In 1907 this seed was limited in amount, and a second culture was, therefore, raised in 1908 from seed of the same parents, but gathered from unprotected flowers. Of these two cultures the former consisted of twenty-one plants all of which were true to type, while of the latter eleven plants were pure and three undoubtedly crosses. In two of these three there was a marked development of sympodial secondary branches and a consequently shortened vegetative period, while in the third case the leaf factor was also intermediate(2·5)

(2) In 1906 the seed of sixty plants was gathered from a field crop of *G. neglectum* Tod. and *G. roseum* Tod. and sown in separate lots in the following year. These included the types (5—9) with both "broad-" and "narrow-" lobed leaves and with yellow and white flowers. The observations on the flower colour of this series are given in Table IV. Owing to the fact that in these types yellow is completely dominant to white it is impossible to detect crosses between yellow and white-flowered plants in the progeny of the yellow forms. Here it is only possible to conclude that the thirty-four plants selected were pure yellows. The white-flowered plants have, however, given seven yellow offspring, and these seven are undoubtedly crosses. Accurate information concerning the leaf form is not available since no determinations of leaf factor were made in this series. A record has, however, been kept in which three groups, broad-lobed, narrow-lobed, and intermediate, have been distinguished. These are tabulated in the second section of Table IV. From this it will be seen that thirty-eight plants out of the sixty gave offspring without impurity; that twelve were themselves pure, but that among two hundred and seventy-five offspring occurred twenty-eight plants which showed clear indications of being the result of a cross, and that the remaining ten plants were themselves impure. Of these last it is only necessary to remark on the paucity of intermediates. At the time these observations were made the leaf factor had not been identified and no means of accurately recognising the limits of the "broad-" and "narrow-" lobed types had been found. There is little doubt, therefore, that many of the forms which, though intermediate in reality, approached one or other extreme, were included among the extreme forms and consequently it is impossible to draw any conclusion from the marked divergence from the normal in the numerical proportion of the groups.

(3) In the cotton season of 1909 considerable damage resulted from the ravages of the boll worm, numbers of the self-fertilised bolls were attacked, and it was feared that loss of promising types might result owing to the reduction of the quantity of seed harvested. A further supply of seed was, therefore, gathered from the same

plants and sown in 1910 as a collateral series which only differed from the first in the one feature that the flowers had not in this case been protected. A third series was also grown from seed gathered at the end of the hot weather, 1910, from the same parents which had been transplanted and cut back early in the year. The second and third series are those termed respectively "early" and "late" series in Table V. The observations collated in this Table are limited to a record of the red sap colour of the vegetative parts of the plants and of the flower colour. In the first series, from self-fertilised seed, as in previous years, plants having the sap colour spreading to the lamina have given pure red offspring only and, similarly, plants in which the red colour is absent (foliage colourless or green) have given colourless offspring only. In both the naturally fertilised series, as Table V shows, a considerable number of impure forms have occurred. Further the colour of these aberrant forms is, with a single exception (not included in the above table as it appears to be almost certainly the result of accidental mixing of seed), the intermediate form, with the red colour only partially developed, which is invariably produced when a pure red plant is crossed by one in which the colour is absent. To pass to the flower colour, it has been shown by numerous experiments that when full precautions have been taken a white-flowered plant invariably breeds pure to this character, but in these two series a certain number of yellows have occurred which can only be the result of natural crossing.

Confirmation, if such were needed, could be obtained from the leaf factor, but in view of their somewhat tedious character, the need did not appear to justify the expenditure of much time on the determinations, which were only made in the case of those plants used as parents and whose purity it was desirable to ascertain as far as possible. A superficial observation, however, was sufficient to indicate that numerous intermediate forms occurred among the offspring of plants which were pure in their leaf character.

The difference in the percentage of impurity as given in Table V for the two series is a matter of some interest. In one case only does that figure for the late series exceed that for the early series,

and in this the number of individuals is too small to admit of much weight being attached to a percentage figure derived from their use. In all other cases the number of crosses occurring in the early series is proportionately high, for, while the combined percentage is approximately eleven for the " early " series, that for the " late " series is 3·5. Now the flowers from which the seed giving the " early " series was derived were open at the end of the rains, a season when the atmosphere is still moist and the temperature not excessive. The late series, however, is derived from fruit set during the intensely hot and dry summer months of April and May. In the former case the abundant insect life of the rains is still present, while in the latter the conditions are such as to reduce this to its minimum. It is reasonable, therefore, to conclude that there exists a close interrelation between the abundance of insect life and the amount of cross-fertilisation and the observation adds weight to the opinion already expressed (p. 47) that the divergent views on the occurrence and extent of cross-fertilisation are to be traced to the difference in climatic condition.

Hitherto the extent to which cross-fertilisation occurs has been considered from the general aspect only. There remains the further problem of the distance at which it may occur. This problem is far more complex, but is also one of great practical importance since the greater the distance at which cottons are found to influence each other, or, in other words, the greater the distance to which pollen is found to be carried, the more intricate must be the precautionary measures taken for extending the culture of new kinds to prevent the swamping effect of accidental cross-fertilisation. In this connection Webber* states that absolute isolation would require a separation of from 5—10 miles, but that practical isolation may be procured at a distance of a quarter to half a mile. If this proves to be the case with the Indian Cottons the difficulties accompanying any multiplication of a pure race on to a commercial scale will be considerable.

* U. S. Dept. of Agr. Year-book, 1902, p. 370.

Opportunity for collecting evidence on this head has been limited, but it is satisfactory to find that, to prevent cross-fertilisation as far as it is possible to draw any conclusion, such distances appear to be unnecessary. Such observations as have been obtained are derived from the 1910 series (early) grown from naturally fertilised seed. In this series, using the red sap, and the flower colour as distinctive characters, the number and character of the crosses occurring in the offspring of each individual separately has been recorded, and the position of each parent plant in the field then traced back and a note made of its distance from the nearest plant capable of giving the particular cross observed. Such details have been obtained for some eighty plants and their respective offspring and tabulated in Table VI while the method is illustrated in Diagrams 1—4.

In the field the plants were ranged in lines 3ft. apart with a distance of 2ft. 6in. between the plants in a single line. Each plant, therefore, is surrounded by eight plants, two at a distance of 2ft. 6in., two at 3ft. and four at a distance approximately 3ft. 10in. These eight plants form an inner circle of neighbours and their branches may intermingle with those of the central plant. In no other case will such intermingling occur though, if the intervening plant dies, a short distance only will separate the plant from plants separated by a distance of 5ft. in one direction or 6ft. in the other.

Table VI may, therefore, be considered as falling into 3 sections: —the first includes all those plants situated within four feet of each other; the second, those separated by a distance greater than four feet but less than 10 feet; and the third, those separated by 10 feet or more. In the first case, as the table shows, crossing occurs with considerable frequency and the same remark applies to the second group. In the latter case, however, with one exception (Diagram 3), the intervening plants have died, and there is, therefore, direct access from one plant to the other. In the third group, if the offspring of a single plant are excluded, no crossing has taken place. In the exceptional case (Diagram 2) distinction can be drawn between the three crosses. In two of them, in addition to the yellow

colour introduced into the flower, the foliage shows the impure condition with the red colour as far as the veins only. These two crosses must have been produced by a cross from a yellow or impure red, parent and the nearest plant of either kind is one with a yellow flower situated at a distance of 10ft. In the third case the full red foliage colour is retained and the cross is indicated by the introduction of the yellow only. This can only be effected by a pure, or by an impure, red. The nearest plant of either kind is a pure red situated at a distance of 13ft.

In Diagram I are given a group of eight plants with their neighbours; though each of the eight is situated within 2ft. 6ins. of at least one plant the cross from which would be recognisable in the offspring, yet in four out of the eight cases no such cross has occurred. The facts here detailed are insufficient to justify any absolute statement, but clearly point to the conclusion that, for practical purposes, there is no objection to cultivating different races in adjoining plots provided the two lines bordering the second race are discarded for the purposes of seed supply. Additional security, and one which might render even this precaution unnecessary, may perhaps be obtained by the separation of two kinds with one or two lines of a crop which flowers freely during the cotton season and will grow under the same conditions as cotton. For this purpose the Indian Sann (*Hibiscus cannabinus*) or *H. Sabdariffa* naturally suggest themselves.

The insects visiting the cotton flower.

It is not proposed to devote more than a cursory glance to this aspect of the subject which, as far as India is concerned, has been investigated in some detail by Burkill.* The diversity of the insect flora in the various cotton tracts of the world prevents the deduction of general conclusions from observations in one area. Such conclusions must be, to a greater or less extent, of local application only. Certain points in this local aspect may, however, be referred to as having some bearing on the experiments above noted.

* Loc. cit.

From the observations just recorded it would appear that in the United Provinces such cross-fertilisation as occurs is the work of some insect with a limited range of flight. Of the two insects most commonly observed at the cotton flower one is a small bee *Apis florea* Fabr.* Towards sunset this bee is to be found in the partially withered flowers, in which it appears to spend the night, to issue on the following morning densely coated with pollen. It is possible that some of this pollen may still be adhering when the flowers first open and undoubtedly pollen then deposited on the stigma is most likely to cause fertilisation, for the anthers are at the time still complete. On the other hand, the period between dawn and the opening of the flower is considerable, and in this period the insect which is strong on the wing would have covered a considerable distance. If the conclusions drawn as to the distance at which cross-fertilisation takes place be correct, it would appear more probable that, by the time the flower opens the insects have freed themselves from adherent pollen and therefore are rarely, or never, the agents of cross-fertilisation.

The second insect commonly met with on the cotton flower is a small beetle, *Carpophilus dimidiatus* Fabr. The range of this beetle is undoubtedly limited and frequently numbers are to be found crawling inside a single flower. In their actions they may be described as clumsy, frequently falling from one portion of the flower to another and in so doing they become densely coated with pollen. They may, moreover, frequently be seen in the morning, having left the withered flowers of the day before, entering the unopened or opening flower by forcing their way between the spirally wound petals. Though a great deal of the pollen is, no doubt, dislodged during the process there seems every possibility that a certain amount may be still adhering when the insect gains the interior of the flower, and if it is then deposited on the stigma, cross-fertilisation is almost sure to occur.

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* For the identification of these insects I am indebted to Mr. H. Maxwell-Lefroy, Imperial Entomologist.

CONCLUDING OBSERVATIONS.

Sufficient has here been shown to warrant two main conclusions, firstly, that a considerable degree of sterility results from self-fertilisation repeated through a number of successive generations; and, secondly, that cross-fertilisation takes place to a considerable extent, though the greater portion of this is limited to neighbouring plants.

The practical bearing of these considerations is of some importance. In the early stages of experimental work, when individual plants are under examination, it is necessary to guard against the effects of cross-fertilisation by protecting the flowers. By so doing, however, considerable danger is incurred of the loss of vigour and even of the loss of the race through sterility. While, therefore, it is not impossible to raise and carry on single plant cultures—and in fact, such has actually been accomplished in the case of most of the types,—such cultures are likely to be of slight practical value. As far as possible, therefore, it appears advisable to avoid such cultures and to rely for purity on the careful selection, combined with roguing, among such plants as are least likely to have been crossed. For this purpose the types must be grown in numbers sufficient to give a fair body of individuals separated by at least 10ft. *and* by intervening plants from individuals of a different type. In this manner a race of Type 7 exhibiting the full vigour of the original stock has been raised. A further method has been attempted in which a set of 40-50 plants of one type have been enclosed by a single net. It is here impossible to exclude all insects, but the number passing through the net is very small, while those enclosed are only able to effect cross-fertilisation between individuals of the same type. The effectiveness of the method still remains to be proved.

It has been shown that, in exceptional cases only, is the cotton crop in any part of India pure and the same may be said to be the case in other countries also. A series of cottons grown from seed from China and Persia have been found to consist of a number of

forms. Balls,* as noted above, has drawn attention to the mixed nature of the cotton crop in Egypt, while the history of the origin of the named varieties of American cottons as far as this is known, sufficiently indicates that in America, too, a similar condition is to be found.† Such a mixed crop no doubt adjusts itself to its surroundings and, under certain constant conditions, will maintain a definite proportion between the various constituents and even in certain cases, appear to be pure. When such a crop is grown under different conditions it is highly improbable that the proportion between the various constituents will remain unaltered. The new conditions will favour one or other of the component types which will, in a short time, become the dominant element of the crop. It will not be inappropriate here to refer to the example afforded by wheat. There have from time to time been recorded frequent instances of the conversion of red, to white, wheat and of bearded to beardless as the result of ' degeneration ' consequent on change of environment. Such cases, when put to the test, are invariably found to be referable to the occurrence of an, at first, inappreciable admixture of the ' degenerate ' form which, when grown under favourable conditions, increases rapidly and may even ultimately swamp the original kind. If such cases are possible with wheats, in which in Europe, where such instances of ' degeneration ' have been recorded, cross-fertilisation is of the rarest occurrence, the danger of this ' degeneration ' occurring in a crop like cotton in which cross-fertilisation has also to be taken into consideration must be far from inappreciable. Instances have been actually recorded in the case of maize and the true explanation of such phenomena with especial reference to these two instances is given by De Vries‡ with much directness. Under these circumstances it appears possible to carry out experiments on the effect of change or environment with pure cultures only, and preferably, with single plant cultures, if such be obtainable. Unless this precaution is

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* Year-book Khed. Agr. Socy., 1906.

† The Cotton Plant, U. S. Dept. of Agr., Exp. Sta., Bull. 33.

‡ Die Mutations Theorie I s. 10, p. 67.

taken the diversity found may in reality only be a manifestation dependent on the occurrence of a small percentage of impurities.*

From very early times repeated efforts have been made to acclimatise various exotic cottons in India. In 1829 a farm was started at Akra for the purpose for which seed was obtained from America, though even before this date importations of seed had been made.† The only trace now to be found of the labour of generations in Northern India is in stray plants and, here and there, a stray field of the American type, the latter either the result of the most recent effort of the Department or of the enterprise of individual land-holders. In the rest of India the result is hardly different, and though in certain areas, as Dharwar, the type has become permanently established, it may be said in general terms that the record of acclimatization is one of failure. That such failure is due to imperfect cultivation may, in part, be true, but it is improbable that this is more than an indirect cause. It is only necessary to consider the early history of such importations to see that, for a short period, the crop is grown successfully and yields freely, and that sanguine hopes are built on the early years of experiment. It is impossible to read accounts of the earlier importations, such as are contained in Royle's Cotton Culture, in the Reports of the Cotton Commissioner and in the Journal of the Agri-Horticultural Society of India without being struck by this fact. The crop at first maintains its standard and subsequently undergoes a more or less rapid degeneration. The similarity between this and the cases of 'degeneration' in wheat is striking, and suggests the possibility of a like cause here.

The American forms of cotton in commerce have been raised to a large extent by selection. By such process the general standard in productivity, in length of lint, or in other desirable characters is raised to a high level, but the less desirable types are not completely eliminated. The improved plant is adapted to the conditions of the American cotton field with its highly developed

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* Cf. Cook U. S. Dept. Agr. Bur. Plant Industry, Bull. 156.

† The earlier experiments in this direction are recorded in Dr. Royle's Culture and Commerce of Cotton in India.

system of cultivation, and may perhaps of itself be able to maintain its dominant position in the mixture of which the crop in reality consists. Frequently, however, this is not the case, and even in its country of origin the dominant position is only maintained by a continuous system of roguing. Such a commercial variety is in the optimum condition to exhibit this phenomenon of 'degeneration' when grown under changed conditions, and when these conditions include, in addition to climatic differences, a less careful cultivation and cessation of the process of roguing, it is hardly a matter for surprise that some of the hardier forms contained in the mixture should assert themselves to the partial or complete exclusion of the finer ones.

The process of acclimatization has consequently been marked in most, if not in all, cases by a deterioration of the produce which has been in many cases attributed to a degeneration of the race,* but it is more probably simply the self-assertion of those impurities which are best suited to the new environment. The problem of the introduction of exotic races, consequently assumes a new aspect. Viewed in this light, the larger the original importation of seed, the less would appear to be the chance of successful introduction owing to the greater difficulty in the control of this process of displacement of one form by another. If acclimatization on a practical basis be possible, it requires, for the development of the conditions most favourable to success, to be carried out in a manner which admits of the detailed work involved in the extraction, testing and multiplication, of the better components as single plant, or, at least, pure cultures. For this purpose a comparatively small importation and a comparatively small area is all that is at first necessary. Whether, under such conditions, it is possible to raise a race of exotic cotton suited to the conditions of Northern India can only be tested by experiment for on this matter the evidence afforded by the past lack of success is irrelevant. It is not desired here to re-awaken hopes which have so frequently been raised in

* Watt, Wild and Cultivated Cottons, p. 199.

the past only to lead to disappointment; there is sufficient scope for the improvement of the races of the truly Indian cottons to render this the most promising line of work as far as Northern India is concerned. If, however, the causes for lack of success in the past are those here indicated, it follows that the possibility, or the reverse, of acclimatising such forms as the higher grades of American or Egyptian cottons remains yet to be proved.*

Since the above notes were submitted to the Press a paper dealing with the Natural Crossing in Cotton and published in the American Breeders' Magazine† has been received. In this paper the author describes certain experiments and observations which he has made with the direct object of ascertaining the amount of cross-fertilisation taking place. He concludes that in N. Georgia at least 20 per cent. with strong probabilities of 40 per cent. of the blossoms are crossed.

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* For a further account of this phenomenon of 'degeneration,' the reader is referred to Section C of Studies of Egyptian Cotton, containing a biological sketch of the cotton crop of Egypt by Balls, in the Year-book, Khedivial Agricultural Society, 1909.

† Allard, Amer. Breeders' Mag. 1, 1910, 4, p. 247.

APPENDIX.

For ready reference a key to the types here referred to by numbers is attached. (Cf. Proc. Royal Socy. B, Vol. 83, 1911).

Monopodial types.

(*a*) foliage green

† Plant glabrous or nearly so, branches ascending, bracteoles triangular with margin entire or dentate, leaf-factor < 2

Type 1. *G. obtusifolium Roxb.*

†† Plant pubescent, branches spreading, bracteoles deeply auriculate or reniform with margin deeply serrate, leaf-factor < 2

Type 2. *G. herbaceum Linn.*

(*b*) foliage red

Plant differing from Type 1 in the colour of the foliage and petals and the leaf-factor which is > 3.

Type 3. *G. arboreum Linn.*

Sympodial types.

(*a*) foliage green

(1) leaf-factor < 2

† leaf commonly with 3 lobes, bracteoles small closely enveloping bud and fruit, petals yellow.

Type 4. *G. indicum Lamk.*

†† leaf lobes 5-7, petals yellow

Type 5.

††† leaf lobes 5-7, petals white

Types 6 & 7.

(2) leaf-factor $>$ 3

† leaf lobes 5-7, petals yellow

Type 8.

†† leaf lobes 5-7, petals white

Type 9.

Types (5)—(9) are included in the *G. neglectum* and *G. roseum* of Todaro.

††† bracteoles large and continuing to grow during development of the boll which is large and many seeded, petals pale yellow.

Type 10. *G. cernuum Tod.*

(*b*) foliage red

leaf-factor $>$ 3, petals red on white

Type 11. *G. sanguineum Hassk. var-minor* of Gammie.

TABLE I.

	TYPE 3.				TYPE 9.				TYPE 6*a*.				TYPE 6*b*.			
	Selfed.		Crossed.		Selfed.		Crossed.		Selfed.		Crossed.		Selfed.		Crossed.	
	No.	Set.	No.	Set.	No.	Set.	No.	Set.	No.	Set.	No.	Set.	No.	Set.	No.	Set.
1906	17	8	...	..	14	7	...	...	10	6		.	20	11	...	...
1907	20	3	6	2	21	9	...	...	22	11	,	..	20	10	...	...
1908	...	...	...	...	10	0	7	3	18	9	..	...	1	0	16	9
															Selfed. No. | Set.	Crossed. No. | Set.
1909	...	...	.	...	..	...	...	...	12	10	13	9	.	...	7 | 3	3 | 3
							32 selfed gave 123 seeds.		54 selfed gave 91 seeds.						10 selfed gave 69 seeds.	

	TYPE 9.		TYPE 6*b*.		
	Plants.	Seed.	Plants.	Seed.	
1910	40	211g	45	325g	Plants of each type under a single net.

Table II.

	F_1 1907.			F_2 1908.		
	Number.	Set.	%	Number.	Set.	%
Type 2 × Type 4	82	35	43	320	66	11
„ 2 × „ 8	152	59	39	..	...	...
„ 3 × „ 4	145	61	42	3666	1541	42
„ 3 × „ 9	124	62	50	1927	828	43

Table III.

(a) Parents ?						(b) Type 3 × Type 4 3·13 1·40				
F_1	Intermediate.					Intermediate. 2·27				
	< 2	$> 2 < 3$			> 3	< 2	$> 2 < 3$			> 3
F^2	9	21			6	64	143			83
Used as parents	4	6			1	..	..			..
	< 2	< 2	$> 2 < 3$	> 3	> 3	< 2	< 2	$> 2 < 3$	> 3	> 3
F_3	8	4	13	8	1	1222 (5)*	784	1602	791	1273 (6)*

* Exceptions in which the limit is not observed.

Table IV.

Parent Character.	Number.	Offspring.		
		Pure.	Impure.	
Flower, yellow Flower, white	34	951	..	
	20	486	..	
	6	173	7	
		Offspring.		
		<2	$>2<3$	>3
Leaf-factor <2	16 3	227 36	.. 8	.. ..
Do. $>2<3$	10	161	47	160
Do. >3	22 9	..	.. 20	777 211

Table V.

		Early Series.				Late Series.			
		Parents.	Offspring.			Parents.	Offspring.		
			Pure.	Impure.	% Impurity.		Pure.	Impure.	% Impurity.
			Lamina.	Veins.			Lamina.	Veins.	
Type 3 × Type 4	Red to Lamina.	5	49	...	...	15	212	...	...
		15	282	60	18·3	1	22	1	0·4
			Colourless.	Veins.			Colourless.	Veins.	
	Foliage, colourless.	7	91	...	..	4	89	...	...
		16	282	44	11·8	5	135	10	4·4
			Lamina.	Veins.			Lamina.	Veins.	
Type 3 × Type 9	Red to Lamina.	13	124	...	...	8	126	..	...
		12	163	35	12·2	13	333	34	7·4
			Colourless.	Veins.			Colourless.	Veins.	
	Foliage, colourless.	14	253	...	...	33	1089	...	
		7	171	27	6·3	12	540	42	2·5
			Flower, white.	Flower, yellow.			Flower, white.	Flower, yellow.	
	Flower, white.	7	98	...	...	5	122	...	...
		2	15	3	2·6	5	271	18	4·6

Table VI.

Distance.	Plants.	Offspring.		% Impurity.
		Pure.	Impure.	
2 ft. 6 in.	20	217	...	
	36	649	133	13
3 ft.	8	108	...	
	5	120	18	7
3 ft. 9 in.	3	89	8	8
5 ft. 9 in.	1	6	1	14*
6 ft.	1	12	...	
	1	36	6	12*
6 ft. 6 in.	1	5	...	
7 ft.	1	11	2	*
8 ft. 6 in.	1	40	...	
9 ft.	1	4	1	*
10 ft.	1	40	...	
	1	34	2	
13 ft.	1	35	1	
17 ft. 6 in.	1	21	...	
20 ft.	1	65	...	
33 ft.	1	68	...	
50 ft.	1	18	...	

Diagram 1—

.	.	r	R	y
			(1)	
.	y	r	y	R
			(2)	
.	.	R	R	r
		(3)		
.	r	R	S	R
		(4)	(5)	
R	y	r	S	.
r	R	r	y	y
	(6)			
s	s	r	R	R
			(7)	
.	.	r	S	y
			(8)	
.	.	r	w	w

(1) 1 cross in 25 plants .. nearest possible cross 2 ft. 6 in.
(2) 3 crosses in 25 plants .. ,, ,, 2 ft. 6 in.
(3) 6 crosses in 30 plants .. ,, ,, 2 ft. 6 in.
(4) no cross effected in 9 plants .. ,, ,, 2 ft. 6 in.
(5) no cross effected in 13 plants .. ,, ,, 2 ft. 6 in.

* Intermediate plants dead.

(6) no cross effected in 6 plants	..	nearest possible cross	2 ft. 6 in.
(7) 2 crosses in 4 plants	..	,, ,,	2 ft. 6 in.
(8) no cross effected in 17 plants	..	,, ,,	2 ft. 6 in.

Throughout these diagrams—

R = foliage and flower full red.
r = foliage with red to veins, flower red on yellow.
S = foliage full red, flower red on white.
s = foliage with red to veins, flowers red on white.
y = foliage green, flower yellow.
w = foliage green, flower white.
. = vacancy.

Diagram 2—

.	.	y	.	w
w	y	.	.	.
.	.	S	.	S
.	S	S	s	
.	.	(S)	.	
S	.	S	.	w
.	S	S	.	.
S	S	S	s	s
S	.	S	.	.
.	R	.	.	R

1 cross by pure red ;	nearest possible cross		..	..	13 ft.
2 crosses by yellow	,,	,,	..	..	10 ft.
1 cross by white	,,	,,	..	..	6 ft. 6 in.

Diagram 3—

S	S	s
S	(w)	s
	channel 2 ft.	
S	w	S
R	r	r

Cross with red not effected ; nearest possible cross 2 ft. 6 in.
2 crosses with yellow in 13 plants ; nearest possible cross 7 ft.

Diagram 4—

.	r	r	R	.
r	.	y	y	.
		(1)		
y	.	y	.	r
		(2)		
.	.	.	.	.
.	.	.	.	.
.	r	r	.	.

(1) 6 crosses in 35 plants ; nearest possible cross .. 2 ft. 6 in.

(2) 6 crosses in 42 plants ,, ,, .. 6 ft.

Intermediate plants dead.

THE INHERITANCE OF RED COLOUR, AND THE REGULARITY OF SELF-FERTILISATION, IN *CORCHORUS CAPSULARIS, LINN.*,—THE COMMON JUTE PLANT.

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FROM 1902 to 1907 we were engaged in making a preliminary survey of the races of jute cultivated in India, and, in the Agricultural Ledger No. 6 of 1907, we gave an account of our results to that date. We had under observation, from year to year, during this investigation, plots representing practically all* the races recognized by the ryots in every part of the two Bengals. These plots were both on the Burdwan Experimental Farm and at the Pusa Research Institute; and in several years they were over one hundred in number. Red races and green ones stood side by side: but the races seemed to reproduce true, after we had weeded out from them the aberrant plants, which sprang from the original, and often very impure, seed which we obtained from the districts.

As a result of our preliminary survey we kept apart thirty-three races of *Corchorus capsularis*, including three grown only

* A new variety, *C. capsularis*, var. *oocarpus*, was discovered by us in 1910 (Jour. Asiatic Society, Bengal, N. S. VII, 1911, p. 465); but no new races of true *C. capsularis* have since been met with.

to serve as a vegetable. The races may be grouped conveniently under the following colour types :—

(*a*) deep red stem, petioles and fruits, with the teeth of the leaves also tipped with red ;

(*b*) brownish red stems, petioles and fruits, with no distinct red borders to the leaves ;

(*c*) green stems with reddish petioles and fruits ;

(*d*) pure green stems, petioles and fruits.

The tints of the various red races contained in group (*a*) or group (*b*) were not, of course, exactly identical ; the members of the groups (*a*), (*b*), and (*c*) rather formed a series of colour gradations between the extreme types—pure red and pure green.

The red colour is a soluble pigment, turning brilliant malachite green with alkali and bright carmine with acid,* found—

(*i*) chiefly in the brick-shaped parenchyma cells, which lie immediately under the epidermis of the stems and petioles ;

(*ii*) in the parenchyma of the petioles, sporadically, even as deep as the phloem ;

(*iii*) in sub-epidermal cells near the margin of the leaf and

(*iv*) in small multicellular hairs on the leaf and on the stipules.

The intensity of the colour of a red-stemmed jute is due to an almost general distribution of the pigment in the sub-epidermal cells of the parts coloured. Conversely, the fewer the pigmented cells the less red the stem ; until, in pure green races, they are absent. Even the stems of members of class (*c*) (green stems with red petioles) shew, under the microscope, a few red cells. There are therefore only two real colour types in jute, capable of exact, ready definition, *viz.* :—red and green ; and the classes (*a*), (*b*) and (*c*) in the colour scheme given above, are convenient but arbitrary divisions of degree in colour, without definite boundary lines.

When a jute seedling appears above ground, whether it be of a red or of a green stemmed race, it is, to the eye, wholly

* A pure green plant—one which, under the microscope, shows no red cells at all—does not give this colour reaction.

green ; though, under a microscope, a few red cells may be detected, in a red race, at the points where the blade and petiole of the cotyledons join. The pigment becomes obvious, later, when it diffuses over the surface of the epicotyl and is visible, if the race be a red one, on the petiole and on the margin of the first leaf after the cotyledons. Succeeding leaves show still more red ; and the epicotyl, stem, and petioles grow redder. This change we shall illustrate by two counts made of the progeny of plants 119 and 214 (what these plants were will be obvious later) : the plants counted were a mixed series grown in two lines : they were examined carefully when a fortnight old and classed into "red stemmed," "pale red stemmed," "green stemmed with red petioles" and "pure green": they were examined again and reclassed when a month old. In the meantime a few belated seeds had germinated, altering the total slightly.

	Red.	Pale red.	Red petioled.	Green.
1st counting ...	148	440	250	253
Later counting ...	250	493	109	259

The figures suggest that approximately 102 plants, classed as pale red stemmed at the first counting, had become distinctly red at the later counting ; 155 plants classed as having only red petioles at the first counting had become pale red at the later counting, and 14 more plants had been added to the red series, either from those considered to be green at the first count ; or, from the 20 new germinations.

The lesson learned from this is that, in order to determine how many red and how many green plants there may be in a bed, it is necessary to wait until the plants have had time to declare themselves.

In 1906 (*vide* the "Journal of the Asiatic Society of Bengal," N. S. II, pp. 515-519) one of us (I. H. B.) gave an account of the jute flower, showing it to be self-fertile and self-pollinated, but that insect visitors go to it. The structure of the flower is such, we shewed, that, unless foreign pollen is prepotent, self-fertilization is not unlikely to result from an insect visit. It was necessary however to have more positive evidence on this point, when

breeding experiments were commenced; because, if cross-fertilization under normal circumstances be at all common, special precautions must be taken, to exclude insects from the parent flowers. The results given below are, we think, sufficient evidence that cross-pollination is rare enough to be ordinarily negligible.

Cross-fertilization with pure types of Red and Green Plants.

In 1908 we took two races of *C. capsularis*, that had been under observation long enough for us to be certain that they reproduced pure, *viz.* :—

(1) Desi of Dacca.
(2) Bhadya Red of Jalpaiguri.

The first has no red colour, *i.e.*, it is pure green throughout; while the second is deep red in stems, petioles and fruits. We cross-fertilized flowers of plants belonging to these races, in both directions, and we selected, from among others obtained in this way, four capsules with good seed, of which, in two cases, a Bhadya plant was the female parent and, in the other two, a plant of Desi.

It was found that, at Pusa, the anthers dehisce about sunrise; so that it was necessary to emasculate the flower of the female parent on the previous evening and to cross it as early as possible the next morning. A bag was tied over the ruptured bud, to protect it during the night; the bag being retained, after pollination, until the capsule began to swell. As a control, a considerable number of other flowers were also emasculated in the evening, but not pollinated on the next morning. No one of these latter set any seed, while the percentage of successes in the case of the crossed flowers was over fifty. Considerably more than four crossed flowers set seed, but the four plants already mentioned were the only ones with which the experiment was continued. The four capsules were numbered 102, 103, 120 and 125 respectively.

In 1909, the seed from each of these capsules was sown, on the 9th July, in pots in the pot-culture house at Pusa and 15 plants in all were raised to maturity, *viz.* :—

3 from No. 102
4 ,, No. 103
6 ,, No. 120
2 ,, No. 125

All these plants had red colour in their stems; thus suggesting that red behaves as a dominant characteristic in jute as apparently it has done in most species of plants where red-stemmed and green-stemmed races have been crossed. It was noticed, however, that the red colour in the hybrid progeny was always less intense than in the parent plant, an observation which has been confirmed by more recent experiments.

The plants were numbered as follows :—

DESCENDANTS OF

102	103	120	125
210 211*a* 211*b*	119 261 262 263	199 201 203 204 206 209	213 214

Several flowers on each of these plants were carefully self-pollinated and good seed was obtained from all plants, excepting Nos. 199 and 204.

This seed was sown, in lines, on the Dacca Farm on May 18th, 1910. At the same time seed, from the same plants respectively, but produced from flowers left to be fertilized naturally,* was sown in adjacent lines. On germination it was seen that the plants, from both selfed and from ordinarily fertilized flowers, varied in colour from red to pure green. When

* Side by side with the pots in which the hybrids were growing were several pots containing pure green jute plants.

a fortnight old, they were counted and classified into the following :—

(*a*) Red stems with red petioles and fruits.
(*b*) Light red stems, petioles and fruits.
(*c*) Green stem with reddish petioles and fruits.
(*d*) Pure green.

When one month old, the plants were again recounted and reclassified. Three counts were made in all.

Table I gives the numbers of the respective colours, at the last count, of the plants grown from seed produced by self-fertilized flowers, together with the ratio of the number of mixed red plants to those of pure green colour :—

Table No. I.

Proportion of red to green plants in the F_2 generation selfed plants.

Number of plants of different Colours.

	Number of flower in 1908.	Number of flower in 1909.	Red stems.	Light red stems.	Green stems with red petioles.	Pure green.	Ratio of red plants all together to pure green plants.
Bhadya ♂ × Desi ♀ ...	103	119	9	10	6	11	2·3 : 1
		261	5	12	1	4	4·5 : 1
		262	10	15	3	5	5·6 : 1
		263	6	15	2	9	2·6 : 1
Bhadya ♂ × Desi ♀ ...	102	210	51	64	15	42	2·9 : 1
		211*a*	25	55	13	28	3·3 : 1
		211*b*	9	20	7	12	3·0 : 1
Desi ♂ × Bhadya ♀ ...	120	201	12	36	6	14	3·9 : 1
		203	8	18	0	6	4·3 : 1
		206	63	106	32	56	3·6 : 1
		209	14	56	9	26	3·0 : 1
Desi ♂ × Bhadya ♀ ...	125	213	7	19	6	10	3·2 : 1
		214	31	67	9	36	3·0 : 1
Total ...	......	...	250	493	109	259	Mean ratio. 3·3 : 1

The table proves that, of the two alternative characters—presence of red colouration and its absence, the first is dominant

and the second recessive, in crosses. Theoretically, the ratio should be 3 to 1, instead of 3·3 to 1 as found.

The seed saved from the selected capsules which had been left to be fertilized naturally gave plants as shown in Table II. The ratio of those with red pigment to those without is almost exactly 3 : 1 in this case.

Table No. II.

Proportion of red to green plants in the F_2 generation, from flowers naturally fertilized.

	Flower number in 1908.	Flower number in 1909.	Red stems.	Pale red stems.	Green stems with red petioles.	Pure green.	Ratio.
Bhadya ♂ × Desi ♀ ...	103	261	47	139	98	96	3·0 : 1
		262	27	78	25	44	3·0 : 1
		263	21	66	16	35	3·0
Bhadya ♂ × Desi ♀ ...	102	210	79	177	177	133	3·3 : 1
		211	44	92	28	47	3·5 : 1
Desi ♂ × Bhadya ♀ ...	120	204	15	42	8	19	3·4 : 1
		206	17	24	3	15	3·0 : 1
		209	50	92	47	71	2·7 : 1
Desi ♂ × Bhadya ♀ ...	125	213	15	20	10	10	4·5
		214	54	76	70	88	2·3 : 1
Total ...	......	.. ...	369	806	482	558	3·0 : 1

F_3 Generation.

No artificial self-fertilizations were made during 1910, but, at the end of the season, seed produced by natural fertilization was preserved from single plants of each type, in each of the plots mentioned in Tables I and II. In the present season, 1911, it was found impossible to sow the whole of the seed thus collected. Attention was therefore confined to the progeny of plants in the following plots, *viz.* :—Nos. 206, 209, 261, 262, and 263, our observations on which are contained in the following pages. The following diagram shews at a

glance the pedigree of the plants detailed in Tables III and IV :—

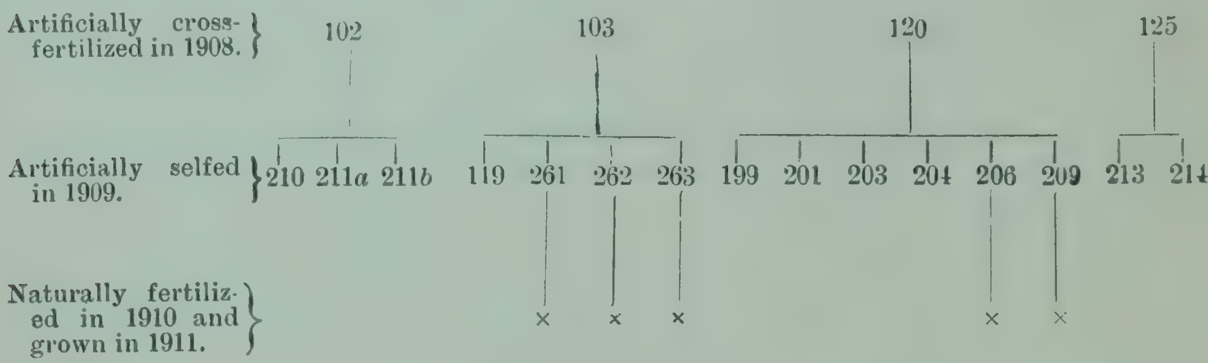

TABLE III.

Descendants, in the F_3 generation, of plants, flowers of which were self-fertilized in the F_1 generation.

		Red.		Green.	Ratio of red to green.
Descendants of plan No. 206.	1,370 plants raised from a deep red plant R_1 were :—	1,018	:	352	2·9 : 1
	2,930 ,, ,, ,, ,, R_2 ,,	2,127	:	807	2·7 : 1
	1,336 ,, ,, pale ,, P_1 ,,	1,000	:	336	3·0 : 1
	1,268 ,, ,, ,, ,, P_2 ,,	951		317	3·0 : 1
	1,371 plants raised from a plant with green stem and red petioles GR_1 were :—	1,038	:	333	3·1 : 1
	1,411 plants raised from a plant with green stem and red petioles GR_2 were :—	994	:	417	2·4 : 1
	2,406 plants raised from a pure green plant G_1 were :—	35	:	2,371	1·0 : 68
	2,401 ,, ,, ,, ,, G_2 ,,	39	:	2,365	1·0 : 60
Descendants of 209.	801 plants raised from a deep red plant, R_1 were :—	632	:	179	3·5 : 1
	581 ,, ,, ,, R_2 ,,	437	:	144	3·0 : 1
	1,210 ,, ,, ,, R_3 ,,	894	:	316	2·8 : 1
	750 ,, ,, ,, R_4 ,,	750	:	0	......
	2,407 ,, ,, pale red P_1 ,,	1,819	:	588	3·1 : 1
	90 ,, ,, ,, P_2 ,,	90	:	0	......
	257 ,, ,, plant with green stems and red petioles and fruits GR_1 ,,	257	:	0	......
	1,007 ,, ,, ,, GR_2 ,,	733	:	274	2·7 : 1
	584 ,, ,, ,, GR_3 ,,	435	:	149	3·0 : 1
	2,528 ,, ,, green plant G_1 ,,	10	:	2,618	1 : 262
	1,588 ,, ,, ,, G_3 ,,	30	:	1,558	1 : 52
	1,892 ,, ,, ,, G_4 ,,	59	:	1,833	1 : 31

TABLE III.—(*contd.*)

Descendants, in the F_3 generation, of plants, flowers of which were self-fertilized in the F_1 generation.—contd.

				Red.		Green.	Ratio of red to green.
Descendants of 261.	1,562 plants raised from a pale red plant,	P_1	were :—	1,175	:	387	3·0 : 1
	1,363 ,, ,, ,,	P_2	,,	1,020	:	343	3·0 : 1
	379 ,, ,, a green stemmed plant having red petioles and fruits	GR_1	,,	379	:	0	......
	805 ,, ,, a green stemmed plant having red petioles and fruits	GR_2	,,	593	:	212	2·7 : 1
	1,054 ,, ,, green	G_1	,,	17	:	1,037	1 : 61
	684 ,, ,, ,,	G_2	,,	19	:	665	1 : 35
Descendants of 262.	1,322 plants raised from a deep red plant,	R_1	were :—	999	:	323	3·1 : 1
	1,734 ,, ,, ,,	R_2	,,	1,313	:	421	3·1 : 1
	201 ,, ,, ,,	R_3	,,	201	:	0	......
	1,958 ,, ,, light red	P_1	,,	1,469	:	489	3·0 : 1
	3,017 ,, ,, ,,	P_2	,,	2,309	:	708	3·3 : 1
	1,892 ,, ,, ,,	P_3	,,	1,423	:	469	3·0 : 1
	619 ,, ,, green stemmed plant with red petioles	GR_1	,,	443	:	176	2·5 : 1
	1,205 ,, ,,	GR_2	,,	911	:	294	3·1 : 1
	90 ,, ,, ,,	GR_3	,,	90	:	0	......
	2,266 ,, ,, green plant	G_1	,,	17	:	2,249	1 : 132
	3,777 ,, ,, ,,	G_2	,,	61	:	3,716	1 : 61
Descendants of 263.	298 plants raised from a deep red plant,	R_2	were :—	298	:	0	......
	1,431 ,, ,, pale red	P_1	,,	1,054	:	377	2·8 : 1
	2,752 ,, ,, ,,	P_2	,,	2,065	:	687	3·0 : 1
	3,368 ,, ,, green stemmed plant with red petioles	GR_1	,,	2,628	:	740	3·6 : 1
	884 ,, ,, ,,	GR_2	,,	659	:	225	2·9 : 1
	332 ,, ,, green plant	G_1	,,	13	:	319	1 : 25
	991 ,, ,, ,	G_2	,,	27	:	964	1 : 36

In the following Tables, IV*a*, IV*b*, IV*c*, it can be seen at a glance that the different types of unfixed red plants of the F_2 generation behave similarly in producing progeny consisting of red plants and green ones approximately in the ratio of 3 : 1.

TABLE IV*a*.

Unfixed dark red plants yielded progeny as follows :—

Name of parent plant.	Number of red plants in progeny.	Number of green plants in progeny.
206.R_1	1,018	352
— R_2	2,127	803
209.R_1	632	179
— R_2	437	144
— R_3	894	316
262.R_1	999	323
— R_2	1,313	421
TOTALS ...	7,420	2,538

Mean ratio of red : green = 2·92 : 1.

TABLE IV*b*.

Unfixed light red plants yielded progeny as follows :—

Name of parent plant.	Number of red plants in progeny.	Number of green plants in progeny.
206.P_1	1,000	336
— P_2	951	317
209.P_1	1,819	588
261.P_1	1,175	387
— P_2	1,020	343
262.P_1	1,469	489
— P_2	2,309	708
— P_3	1,423	469
263.P_1	1,054	377
— P_2	2,065	687
TOTALS ...	14,285	4,701

Mean ratio of red to green = 3·04 : 1.

TABLE IV*c*.

Unfixed plants, having green stems with red petioles and fruits yielded progeny as follows :—

Name of parent plant.	Number of red plants in progeny.	Number of green plants in progeny.
206.GR_1	1,038	333
— GR_2	994	417
209.GR_2	733	274
— GR_3	435	149
261.GR_2	593	212
263.GR_1	2,628	740
— GR_2	659	225
262.GR_1	433	176
— GR_2	911	294
TOTALS ...	8,424	2,820

Mean ratio of red to green = 2·99 : 1.

Another diagram will serve to make clear the origin of the next series of plants : descendants, in the F_3 generation, of plants, flowers of which were allowed to fertilize naturally in the F_1 generation (vide Table II). The reader will note that in 1909 their grandparents were naturally fertilized, and not artificially selfed as were those of the preceding series.

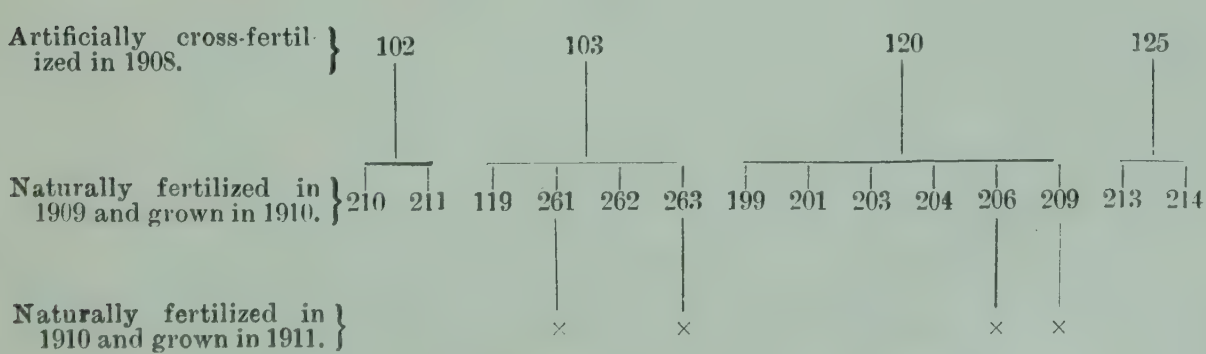

Table V.

Descendants F_3 generation of the plants mentioned in Table II, and of which the pedigrees are given in the above diagram.

				Red.		Green.	Ratio.
Descendants of 206.	1,651 plants raised from a deep red plant	R_1	were :—	1,254	:	397	3·2 : 1
	1,926 ,, ,, ,, ,,	R_2	,,	1,419	:	507	2·8 : 1
	1,030 ,, ,, light red ,,	P_1	,,	835	:	195	4·3 : 1
	1,600 ,, ,, ,, ,,	P_2	,,	1,600	:	0	——
	64 ,, ,, green plant	G_1	,,	1	:	63	1 : 63
	1,157 ,, ,, ,, ,,	G_2	,,	15	:	1,142	1 : 76
Descendants of 209.	1,025 plants raised from a deep red plant	R_1	,,	782	:	243	3·2 : 1
	801 ,, ,, ,, ,,	R_2	,,	801	:	0	——
	567 ,, ,, ,, ,,	R_3	,,	407	:	150	2·8 : 1
	1,389 ,, ,, light red ,,	P_1	,,	1,389	:	0	——
	1,199 ,, ,, ,, ,,	P_2	,,	899	:	300	3·0 : 1
	904 ,, ,, ,, ,,	P_3	,,	904	:	0	——
	670 ,, ,, green plant	G_1	,,	2	:	668	1 : 334
	1,374 ,, ,, ,, ,,	G_2	,,	12	:	1,362	1 : 113
	1,379 ,, ,, ,, ,,	G_3	,,	10	:	1,369	1 : 137
Descendants of 261.	896 plants raised from a deep red plant	R_1	,,	662	:	234	2·8 : 1
	1,219 ,, ,, ,, ,,	R_2	,,	931	:	288	3·2 : 1
	1,090 ,, ,, light red ,,	P_1	,,	792	:	298	2·7 : 1
	752 ,, ,, ,, ,,	P_2	,,	568	:	184	3·1 : 1
	1,105 ,, ,, green ,,	G_1	,,	8	:	1,097	1 : 137
	1,247 ,, ,, ,, ,,	G_2	,,	14	:	1,233	1 : 88
Descendants of 263.	1,148 plants raised form a deep red plant	R_1	,,	865	:	283	3·1 : 1
	1,184 ,, ,, ,, ,,	R_2	,,	899	:	285	3·1 : 1
	1,098 ,, ,, light red ,,	P_1	,,	1098	:	0	——
	1,088 ,, ,, ,, ,,	P_2	,,	830	:	258	3·2 : 1
	1,330 ,, ,, green plant	G_1	,,	27	:	1,303	1 : 49
	228 ,, ,, ,, ,,	G_2	,,	8	:	220	1 : 28

Table VI gives an analysis of the results for unfixed reds included in Table V.

Table VI*a*.

Unfixed dark red plants yielded progeny as follows :—

Name of parent.	No. of red plants in progeny.	No. of green plants in progeny.
206.R_1	1,254	397
— R_2	1,419	507
209.R_1	782	243
— R_3	417	150
261.R_1	662	234
— R_2	931	288
263.R_1	865	283
— R_2	899	285
Totals ...	7,229	2,387

Mean ratio of red to green = 3·03 : 1.

Table VI*b*.

Unfixed light red plants yielded progeny as follows :—

206.P_1	835	195
209.P_2	899	300
261.P_1	792	298
— P_2	568	184
263.P_2	830	258
Totals ..	3,924	1,235

Mean ratio of red to green = 3·17 : 1.

Taking a grand total of all the progeny in the F_3 generation from unfixed red plants of the F_2 generation we get :—

	Total of red plants in progeny.	Total of green plants in progeny.	Ratio of red to green.
Table IV*a*.	7,420	2,538	......
Table IV*b*.	14,285	4,701	......
Table IV*c*.	8,424	2,820	......
Table VI*a*.	7,229	2,387	......
Table VI*b*.	3,924	1,235	......
Grand Total	41,282	13,681	3·02 : 1

Thus, in a total of 54,963 plants of the F_3 generation, produced from unfixed reds of the F_2 generation, the ratio of red plants to green ones is almost exactly as 3 : 1.

Fixed Red Plants.

In Tables III and V, it will be seen that a number of plots in the F_3 generation contained no green plants, *viz.* :—

$$\left.\begin{array}{r}209.R_4\\ -\ P_2\\ -GR_1\\ 261.GR_1\\ 262.R_3\\ -GR_3\\ 263.R_2\end{array}\right\}\text{Table III.}\qquad\qquad \left.\begin{array}{r}206.P_2\\ 209.R_2\\ -\ P_1\\ -\ P_3\\ 263.P_1\end{array}\right\}\text{Table V.}$$

In none of these plots is a single green plant to be found and the plants are therefore, presumably, fixed with reference to the inheritance of red colour. On the other hand, as regards degree of colouration ; while two or three plots contain practically only one type of red plant, the plants in the majority of these plots, as was the case with the red plants of the F_2 generation (Tables I and II), are a mixture of the several shades of red, enumerated at the commencement of this paper (p. 1, types *a*, *b*, *c*). Differences of such magnitude as these, if hereditary, have hitherto been held to constitute the distinction between one race and another.

In the following Table No. VII it will be seen that one of the plots (No. 263.R_2) contained practically only dark red plants, while in a second (No. 262.R_3) were 85 per cent. of dark red plants. In a third plot all the plants had green stems with red petioles and fruits. Thus, in the latter case, by crossing a pure green jute with a dark red one, it has been possible to produce, pure and fixed, a common intermediate colour type, an interesting fact which suggests that the origin of the other intermediate races of jute, at present under cultivation in Bengal, might also, possibly, be traced to hybridization.

An attempt has been made to count the representatives of each shade of red in the plots containing only red plants; but an accurate classification has been found almost impossible, owing to the number of colour gradations and the difficulty experienced in apportioning them under the right heads. The figures are probably therefore not very reliable on this account; but they are reproduced here for what they are worth.

Table VII.

Shewing the approximate number of plants of different shades of red in plots (F_3 generation) containing no pure green plants :—

Number of plot.	Number of Plants.		
	Dark red.	Light red.	Green stems with red petioles and fruits.
209.R_2	249	**473**	79
209.R_4	87	112	**233**
262.R_3	**173**	12	16
263.R_2	**293**	0	8
209.P_1	2	331	**1,078**
209.P_2	49	51	**84**
209.P_3	233	**715**	0
206.P_2	418	386	**1,259**
263.P_1	256	**446**	395
209.GR_1	0	157	**454**
261.GR_1	210	238	**468**
262.GR_3	0	0	**90**

Of these No. 262.GR_3 is a pure plot of green stemmed plants with red petioles and fruits. No. 263.R_2 is a practically

pure dark red plot and No. 9 contains about 85 per cent. of dark red plants. In the remainder there is no satisfactory approximation, either to one shade of red, or to a constant ratio between the different types. We hope to pursue this point further. In the present season (1911), the seed was sown rather too close together in the plots; so that it was found necessary to thin out a number of plants when they were about six weeks old. At this stage, while it is perfectly easy to distinguish between a pure green plant and one containing red colour, it is more difficult to say whether a red plant of a particular shade will retain its colour in unchanged intensity, throughout its growth. Of course, the thinning, just referred to, involved an immediate classification of the plants taken out, and it is just possible that an error has crept in here, as some of the plants counted at the time of thinning might have been apportioned differently at a later stage. Next season, arrangements will be made for the plants to be far enough apart in the plots to avoid the necessity for thinning.

In discussing the question of change of colour, it is worthy of note that exposure to sun-light appears to have a certain effect in deepening the red colour in a plant. For instance, the upper portions of a plant in the centre of a well-grown plot are the only ones which receive any large amount of direct sun-light. It is often seen that, under such conditions, the upper branches of a plant, which contains only a small amount of red colour, have a distinctly pink tinge; while its stem, in the shade, appears pure green. On the other hand, plants in the outside of the same plot often shew a trace of pink in their stems also.

DESCENDANTS, IN THE F_3 GENERATION, OF PLANTS WHICH WERE PURE GREEN IN THE F_2 GENERATION.

Seed from the following plants produced a majority of green plants in the F_3 generation. The relative number of green and red plants given in Tables III and V are reproduced in Table VIII.

Table VIII.

Shewing the extent of impurity, consisting of red plants, in plots which should have been pure green.

Name of Plants.		Number of red plants.	Number of green plants.	Ratio of red to green.
Table III.	206.G_1	35	2,371	1 : 68
Do.	——G_2	39	2,365	1 : 60
Do.	209.G_1 ..	10	2,618	1 : 262
Do.	——G_3	30	1,558	1 : 52
Do.	——G_4 ..	59	1,833	1 : 31
Do.	261.G_1	17	1,037	1 : 61
Do.	——G_2	19	665	1 : 35
Do.	263.G_1	13	319	1 : 25
Do.	——G_2	27	964	1 : 36
Do.	262.G_1 ..	17	2,249	1 : 132
Do.	——G_2 ..	61	3,716	1 : 61
Table V.	206.G_1	1	63	1 : 63
Do.	——G_2	15	1,142	1 : 76
Do.	209.G_1 ...	2	668	1 : 334
Do.	——G_2 ...	12	1,362	1 : 113
Do.	——G_3	10	1,369	1 : 137
Do.	261.G_1	8	1,097	1 : 137
Do.	——G_2	14	1,233	1 : 88
Do.	263.G_1	27	1,303	1 : 49
Do.	——G_2	8	220	1 : 28
	Totals ...	424	28,151	
Mean ratio of red to green	... ...	......	...	1 : 66

This is equivalent to an amount of red impurity in the green plots averaging 1·5 per cent.

In the F_2 generation the green plants were surrounded by pure and impure reds in the ratio of 3 : 1. The pure reds, the number of which was presumably equal to about half that of the impure ones, would, on crossing with the green plants, produce only

red progeny; similarly, the impure reds would produce red and green progeny in equal numbers. It may therefore be assumed, that the 1·5 per cent. of red plants found in the green plots, represents about $\frac{2}{3}$ of the total amount of impurity which would actually have been produced, if all the red plants had been pure. In the latter case, the amount of impurity found might be rather more than 2 per cent. Arguing on this basis, it follows that, under the most favourable circumstances for cross-fertilization, jute would tend to breed true to the extent of about 98 per cent. As a matter of fact, our experience in growing pure single plant cultures of different colours, in adjacent blocks, leads us to believe that the amount of crossing which takes place, under ordinary conditions, between neighbouring fields for instance, is probably much less than 2 per cent. In 1909, fifty single plants of several different colour types were selected. In 1910, the seed from each plant, sown separately in adjacent plots, reproduced the parent type absolutely true in every case. Thirty-five out of forty-seven of these plots contained only pure red plants, the remainder being pure green. Immediately adjacent were plots of the F_2 generation of hybrids already described in this paper. Thus, in the presence of abundance of insects at the time of flowering,* there was no lack of facilities for chance crossing between plants in the green plots and those in the surrounding red ones; and the percentage of red plants, in the progeny raised from the seed of the green plots, should therefore be an index of the extent to which chance crossing takes place under these circumstances.

In the present season 1911, seed from these green plots has been sown in $\frac{1}{100}$th acre plots and the number of red plants found in the latter has been counted. The results of the counts, together with the corresponding percentages of red impurity, are given in Table IX. The average number of plants in a $\frac{1}{100}$th acre plot may be taken as about 1,500.

* Both at Púsa and Dacca, insects, particularly *Apis florea*, *Linn.*, are abundant visitors to the flowers of *Corchorus capsularis*.

TABLE No. IX.

No. of plot.	No. of red plants found.	Percentage of impurity.
12.*b*	0	0
19.*b*	2	0·13
27	2	0·13
49	1	0·07
55	40	2·50
57	4	0·25
58	0	0·0
59	1	0·07
60	2	0·13
65	3	0·2
66	0	0·0

Even these figures probably give an exaggerated idea of the amount of crossing which takes place between one field of jute and another. The excessive number of red plants in plot 55 is probably due to accidental contamination of the seed before sowing.

CONCLUSIONS.

From the data in this paper we conclude that :—

(1). When a pure green jute, *i.e.*, one containing no red colour, is crossed with a fixed red plant, or *vice versâ*, Mendel's law is obeyed, the red acting as a simple dominant.

(2). The F_1 generation of hybrids appears to consist entirely of plants of one tint of redness, which, it should be noted, is less dense than the colour of the red parent. The red plants of the F_2 generation, on the other hand, vary widely in the amount of red colour they contain. Moreover, seed from red plants of the F_2 generation has produced progeny of the F_3 generation which, though apparently quite fixed as regards possession of red colour, shews, in most cases, the same variation between individuals in regard to the intensity of red colouring, as characterized the red plants of the F_2 generation.

(3). The facts (*a*), that one result of these experiments has been to produce examples, fixed or unfixed, of all the intermediate colour types of jute hitherto met with, including a pure fixed culture of one of the commonest of these ; (*b*) that

we have shewn a small amount of chance crossing to be possible, are reasonable evidence in favour of tracing, to chance hybridization, the origin of the intermediate coloured races of jute in common cultivation.

(4). Self-fertilization is, nevertheless, the rule in the species; and, while chance crossing probably does take place to a small extent, it is not likely to exceed 2 per cent. (*i.e.*, about 98 per cent. of the plants would tend to breed true), under the most favourable conditions for the production of cross-bred plants. Indeed, there is evidence to shew that, in ordinary circumstances, the amount of chance crossing may not be much greater than 0·2 per cent.

(5). It would appear therefore that, in carrying out breeding experiments with jute, there is little need for elaborate precaution to prevent cross-pollination; and that no more than ordinary care would be necessary to preserve a superior race of jute from contamination by adjacent inferior crops.

OBSERVATIONS ON CERTAIN EXTRA-INDIAN ASIATIC COTTONS.

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INTRODUCTION.

THE cultivation of cotton is restricted to tropical and subtropical countries, and the limiting factor which prevents cultivation in more northerly regions is one of temperature. A second factor of equal importance, in that it may assume the position of a limiting one, is moisture. Though the natural moisture is, in many cases, reinforced by irrigation, and cotton is consequently grown in tracts where the rainfall is deficient, in other tracts this is not so and here cultivation will be restricted to the regions of sufficient rainfall. Throughout Asia, from Arabia in the West to China on the East, cotton is grown wherever sufficiently favourable climatic conditions are to be found. There is thus a continuous tract of country bordering the Northern limit throughout which cotton is found to a greater or less extent, and of which Northern India forms the central portion, separated from the two wings by the mountainous country of Afghanistan and Assam. To the West lie Persia and Arabia, separated by no marked geographical or climatological feature from Egypt, and to the East the countries of Siam and China. From this aspect Northern India more nearly agrees with these countries

than with Southern India, from which it is separated by no marked geographical feature, and where the limiting factor to cotton growth is one of moisture. It appeared, therefore, a matter of some interest to compare the cottons of Northern India with those grown to the East and to the West, and in consequence an attempt was made to grow as representative a collection of cottons from these regions as could be obtained.

Through the courtesy of Col. Prain, F.R.S., Director, Royal Botanic Gardens, Kew, seed was received from countries extending from Persia on the West to China on the East, and this was grown during the seasons of 1910-1911. To Col. Prain as well as to the various Consuls in Persia, too numerous to mention individually, to the Siam Department of Agriculture and to the Superintendent, Botanical and Forestry Department, Hong-Kong, from whom the numerous samples of seed have been received, the writers desire to record their indebtedness.

(1) THE PERSIAN COTTONS.

These cottons, as far as they have been observed, fall into two groups. The first of these includes those types falling into Todaro's group *Sub-sectio Indica* (Watts' Section II, Fuzzy Seeded cottons with United Bracteoles), which may be termed the Asiatic group of cottons, while the latter belongs to that author's *Sub-sectio Magnibracteata* (Watt's Section III, Fuzzy Seeded cottons with free Bracteoles). To this latter belong those types which are found widely cultivated in Egypt and America, and members of this group are also found in India. The representatives of this latter group, both in India and Persia, are most closely allied to the American types of Upland Cotton, *G. hirsutum*, L. That this is so in the case of India is not surprising. For more than a century there have been repeated importations of cotton seed from America which have left their mark on the country in the wide distribution of scattered plants of this type, though its cultivation on an extended scale is only here and there maintained. The presence of this type in Persia is not so readily understood. The transportation of seed of agricultural plants has constituted a marked feature of caravan routes in time past, and in countries where these form the sole line of intercommunication, and it is, therefore, somewhat surprising that the Egyptian types, with their great reputation, have not found their way to Persia by this means. The single recorded case of an attempt to grow the Egyptian plant appears to have resulted in failure (*see* below, p. 109).

The types belonging to the former group are not numerous and are all closely related to *G. herbaceum*, Linn. This specimen is described under this name by Parlatore* and Todaro,† by the

* Sp. dei Cotoni.

† R.l. Cult. dei Cotoni.

former of whom it is accurately illustrated.* It is probably one of the earliest known in cultivation and is the form found in certain of the countries bordering the Northern Mediterranean coast, including the Crimea, South Italy, Sicily and Spain. Its home appears to be in Mesopotamia whence it most probably spread to these countries.†

In India a plant which is in many respects closely similar, and is described by Gammie‡ under the same name, though placed by Watt§ under *G. obtusifolium*, Roxb., is found in the Bombay Presidency and yields the so-called long-stapled cottons of India, such as Broach. From this, however, the Persian types differ in one important point, namely, the character of the secondary branches. In more than one earlier publication|| attention has been drawn to the difference between the vegetative and reproductive branches of the cotton plant, and to the relation which exists between the length of the vegetative period and the type of the secondary branches. The vegetative branches are monopodial and, consequently, if the secondary branches are sympodial, the plant will commence to flower as soon as these are formed. If, on the other hand, these branches are monopodial, flowering will be delayed until the appearance of the tertiary branches. Roughly, this difference in the length of the vegetative period may be placed at below 100 days for types with sympodial secondary branches, and at 200 days or over for those with monopodial secondary branches.

A difference of like nature is found to occur between the Indian and Persian types of the series now under consideration. In the Indian types the secondary branches are monopodial and the types consequently late flowering; while, in the Persian types, these are, with the exception of a few basal branches, all sympodial, and these types are, therefore, relatively early flowering. In this difference lies the explanation of the cultivation,

* Rel. Cult. dei Cotoni. Tav. I.

† Watt: The wild and cultivated cottons of the world.

‡ The Indian Cottons; Memoirs, Dept. of Agr. in India, Bot. Series, Vol. II, No. 2.

§ *Loc. cit.*

|| *Jour. As. Soc., Bengal*, New Series IV (208), 1; *Journal of Genetics*, I (1911), 3.

near the northern limits of cotton production and in a country characterised by a comparatively short hot weather and by a cold winter of types, which, in the forms known to the author, were characterised by their prolonged vegetative period. From the details of cultivation which were, in many cases, kindly submitted with the seed, it appeared that the vegetative period did not, in Persia, exceed 120 days. It was further apparent from these details that the custom of breaking off the apex of the main stem is common, if not general. Such action naturally promotes an increased development of secondary branches and also an early production of tertiaries to which this early habit might be attributed. The information was not, therefore, sufficiently definite to outweigh the impression, earlier formed, that these cottons would prove to have an extended vegetative period and the seed was sown early in the season (May 4th), with the object of procuring a lengthened season for the development of reproductive branches before the cold weather set in. Experiment has, however, proved this to be incorrect and, in consequence of the early sowing, considerable injury resulted from the coincidence of the flowering period with the rains.

Such, in outline, is the main characteristic of the *herbaceum* series of Persian cottons. A closer inspection, however, discloses certain points of considerable interest which again centres in the habit of the secondary branches.

In the Indian cottons the secondary branches are either pure monopodia or pure sympodia. In the latter case the apical bud develops at each node into a flower bud, vegetative growth being continued by the development of the main axillary bud. In the Persian forms, on the other hand, the development of the apical bud does not invariably take the form of a flower bud. Here the growth of the apical and axillary buds into two vegetative shoots of approximately equal vigour may result, in which case the shoot arising from the apical bud will be displaced from the direct line of growth of the shoot owing to the vigorous growth of the axillary bud (Plate I). But such equality does not always result, in some cases it is the development of the apical bud that is more

vigorous, in others that of the axillary bud. It is, therefore, possible to consider such branches from a double aspect. In the first instance the development of the apical bud forms the branch, which is, thus, a monopodium bearing tertiary branches ; in the second, the branch is formed of the internodes developed from the successive axillary buds, with false tertiary branches developed from the apical buds. The difficulty of determining which of these two definitions most accurately describes the condition is most marked when this dual development takes place at the first (proximal) node of the branch and the two limbs are equally developed. Frequently, however, this does not occur till the second node and in such cases the secondary branch definitely starts as a monopodium (Plate I).

Such a development is totally distinct from, though in outward appearance, owing to subsequent torsion, very similar to, a condition frequently met with in the Indian types, especially *G. cernuum*, Tod. Here the accessory bud of the sympodium develops (Plate II). The branch produced from this bud is invariably a monopodium and if, as frequently happens, the flower bud formed by the development of the apical bud falls, the condition can only be distinguished by the presence of the scar.

Occasionally the dual development, or false dichotomy, takes place at a series of successive nodes (Plate III). In such cases the branch is most aptly termed a sympodium, for otherwise the tertiary and subsequent branches must all be considered monopodia—a condition which has not been observed in any of the *Gossypia* studied. In isolated cases the branching becomes still more diverse. Plate IV illustrates one such instance. In this case the secondary branch is composite. The axillary bud at the second node carries on the growth, the apical bud giving rise to a weak monopodium only. The branch illustrated in Plate V is still more complex ; considered as composed of the stronger of the shoots arising at each node, it starts as a sympodium, continues as a monopodium with a series of sympodial tertiary branches and ultimately ends in a sympodium.

These forms probably constitute a link—lacking in the Indian cottons—between the monopodial types, in which the secondary branches are pure monopodia and the sympodial types with pure sympodial secondary branches. From the description given by Todaro of his *G. herbaceum* it is clear that the plant to which he refers is a sympodial type. He says they (the branches) "grow in a zig-zag tortuous manner, one internode making a small angle with another," a description which accurately defines the form of a sympodial branch, but from his description of *G. wightianum* it is not clear whether this plant has monopodial or sympodial secondary branches. There appears to be small doubt that the Persian types approach, and in certain cases very closely approach, the form grown in Southern Europe and described by Todaro as *G. herbaceum.* The form from S. Europe is only known to the authors from an entire plant preserved in the herbarium of the Botany School, Cambridge University; in this only sympodial secondary branches are developed.

In this diversity of the form of secondary branching is to be found the most distinctive character of the various Persian types, but in one other feature also they appear to differ with some definiteness. In all observed species of *Gossypia* there occur two buds in the axil of each leaf, one of which is the main axillary bud, and to this the other is accessory and lateral. This accessory bud may remain dormant or may develop and, in the latter case, gives rise to a monopodium (Plate VI). In certain types development of the accessory bud appears to be a definite feature, and in many cases the branch thus produced is far more vigorous than that developed from the main bud. This is especially marked where the main axillary bud forms a sympodium, which is, in such cases, frequently reduced and in extreme cases withered. The true relation of the branches is, here, readily determined by close inspection from the fact that the smaller branch is sympodial—a condition which has never been found in the branch from an accessory bud—and from the relative position of the two branches. As has been shown, the position of the accessory bud in relation to the main axial bud is constant

for a particular branch. From the upper branches the relative position of the main and accessory buds may be determined, and from this the main or axillary nature of the branches situated lower on the stem ascertained.

Lastly, a single instance has been found of a type in which the plant appears to possess two sympodial branches arising from the same leaf axil, one of which develops strongly, while the second gives a single, or at most two, nodes bearing flower buds. This condition appears at first sight to constitute an exception to the rule that the accessory bud gives rise to a monopodium only. At the base of the second, or dwarf, sympodium, on the side removed from the main sympodium, occurs a small leaf or bract, while between the two branches is found a bud. This bract, therefore, constitutes the first leaf of a monopodium developed from the accessory bud, and of which the first internode is reduced and the apical development arrested. The sympodial branch which apparently arises from the accessory bud is, thus, in reality, the tertiary branch arising from the axil of the first leaf of a much reduced monopodium. The same development is found at many of the nodes of the secondary sympodial branches, the accessory bud here giving rise to an apparent sympodium (Plate VII).

Further differences have been observed in the length and thickness of the sympodial branches. In the typical form the internodes are relatively short and the branch is of limited growth. The branch thus formed is spreading or slightly ascending. In certain cases, however, there occurs a marked development of secondary thickening. The branch in these cases loses the 'zig-zag' habit described by Todaro and, owing to the additional rigidity thus obtained, becomes sharply ascending. In general appearance the plant resembles the pure monopodial form found in India, from which, however, it is quite distinct. It has, moreover, a long vegetative period, for where such secondary thickening occurs, the apical bud either fails to develop entirely or withers after a rudimentary flower bud has been formed. In other cases the branches continue to develop;

but remain thin with relatively long internodes. Such branches are incapable of supporting their own weight and the plant becomes definitely scandent.

The fruit is invariably globular, with a sharp mucronate apex, and more or less covered with small glands which appear as black dots. In one instance the fruit was markedly distinct. In size it was considerably larger than the typical fruit, without glands and suffused with a rich red colour.

Owing to the climatic conditions under which they were grown, the produce was small and in several cases nil. It has been found impossible, therefore, to deal with the lint characters of this series. Certain forms, however, are characterised by the possession of a khaki coloured lint, and in this particular differ from the majority of the forms in general cultivation.

From the observations of which the main features have been given above, this series of cottons may be provisionally grouped in the following manner. That this classification can be considered final is not suggested. The observations on which it is based have been limited to a single season, and it is not known how far the characters relied on for division are definite and inherited. Nevertheless there are not wanting signs that these characters are of this nature and distinct, for in many cases the samples sent appear to be nearly pure and true to one type or the other, a condition which is not readily associated with variation in the characters used for the determination of purity.

'HERBACEUM' SERIES OF PERSIAN COTTONS.

(*a*) Apical bud at each node of the secondary branch developing into a flower bud—

(1) Sympodial branches weak and having the typical zig-zag manner of growth described by Todaro ... ... *Type* 1

(2) Sympodial branches, at least the lower ones, strong with marked secondary thickening owing to which the branch becomes straight and simulates a monopodium ... ... *Type* 2

(3) Characters as in (1) but with a marked development of the accessory buds as monopodia ... ... *Type* 3

(4) Accessory buds in appearance developing as sympodia ... *Type* 4

(*b*) One or more apical buds of the sympodium developing into a monopodium, giving to the branch an appearance of dichotomy.

Accessory bud dormant—

(1)	... ...	*Type* 5

Accessory bud forming a monopodium—

(2)	Branches erect or spreading	*Type* 6
(3)	Plant scandent	*Type* 7
(4)	With characters of (2) but with large red eglandular fruit ...	*Type* 8

It appeared possible at first to distinguish two types of dichotomous branching according to whether this takes place at the first or second node of the secondary branch. Though, however, there appears to be a definite tendency in many cases for this development to take place at the same relative node in any particular plant, and in their extreme development the two characters are quite distinct; intermediate forms, in which no such definiteness is apparent, are not uncommon. The division cannot, therefore, be made without further investigation of the point.

In the above table reference to the series of cottons with khaki lint has been omitted. The whole of this series suffered severely from the excessive humidity of the rains, and in several cases it has been impossible to identify the type to which they belong. It cannot be said, therefore, with any certainty whether each, or only a few, of the above types is represented by a race with khaki lint.

The second group of Persian cottons are, as has been noted above, related to the American *hirsutum* forms. The main character in which they appear to differ is in the fuzz which may be present or absent and, in the former case, white or green. There appear to occur considerable fluctuations in the length of lint.

THE COTTONS OF WESTERN PERSIA.

1. Received from H. B. M.'s Consul, Kermanshah.

As far as information is available, this is the only kind grown in this district.

The crop consisted of a mixture of Types 5, 6 and 8, of which type 5 preponderated. In this sample only were a few specimens of Type 8 found.

2. Received from H. B. M.'s Consul, Ahwaz.

A sample of cotton grown in Dizful. Noting on this and the two subsequent samples, he writes :—

"Sowing takes place from the 21st March to 21st April. The seeds are first cleaned of all adhesions of cotton, the presence of which, the Persian cultivators say, prevents germination. The ground is ploughed to a depth of 4" and watered. The seed is then sown and the ground harrowed over. Sprouts show in 6 days and the cotton is picked about 3 months later, the ground being irrigated in the interim.

Plants last two seasons, after which they are renewed."

The sample consisted of Type 5, and in nearly every case the false dichotomy took place at the second node. Associated with this were a few plants of the *hirsutum* form with fuzzless seeds.

3. Received from H. B. M.'s Consul, Ahwaz.

Cotton grown at Dizful where it is termed Parbat-i-Hindi (Indian cotton). The seeds are said to have been obtained from India.

This is a *hirsutum* type with naked seeds. The sample also contained a few fuzzy seeds which gave plants in other respects similar to the main crop.

4. Received from H. B. M.'s Consul, Ahwaz. Cotton grown at Shushtar.

The crop proved to be a mixture of Types 1, 3 and 5, only a small proportion of the latter, however, being present.

5. Received from H. B. M.'s Acting Consul, Mohammerah.

Cotton grown in the vicinity of Shushtar and known locally as *Katti*. This sample consists of a mixture of Types 5 and 6 ; from it have been obtained plants with the most complex series of branching including those to which reference has been made above.

6. Received from H. B. M.'s Acting Consul, Mohammerah.

Cotton grown in the vicinity of Shushtar. As suggested by the sender, this proved to be the same as the last, a mixture of 5 and 6.

7. Received from H. B. M.'s Consul, Ahwaz.

The crop consisted of Type 1 in a nearly pure condition, a few plants only of Type 3 being present.

8. Received from H. B. M.'s Vice-Consul, Bushire. Concerning this cotton the following information was supplied :—

"I am told it is the usual and practically the only kind grown at Bushire, where the cultivation is now very reduced and restricted to a small part of the island."

"The seed is sown in spring and the pods will be ready for picking the summer of the following year."

The crop consisted of a large proportion of Type 2.

9. Received from H. B. M.'s Acting Consul, Shiraz.

Concerning the cultivation of this cotton the following information has been kindly supplied :—

"Sowing takes place 40—70 days after Nauroz (March 21st). Plough 3 times, manure if required (human if obtainable). Sow either (*a*) in furrows after 2 ploughings and then turn over furrows with plough ; or (*b*) after 3 ploughings, soil being then divided up into 'kurzehs,' seed thrown in soft soil."

"Clean seed with ashes."

"Water once, level off with ox beam. Water again after about 40 days. Weed carefully. Water once every 12 days and keep weeded. After 4th watering pick off top

buds to make plant widen out; towards the end of Mizan (October 24) water is cut off and plucking begins some 10 days later."

"There is only one kind of seed."

"Diseases—Shifteh شفته (*a*) attacks the stem and withers the plant; (*b*) attacks the bolls." (I have not seen this; it seems to be a blight.)

"Worm Riha (ريه) (? Bollworm) usually due to bad manure, especially horse and donkey."

The crop appeared to be composed entirely of Type 7.

COTTONS FROM CENTRAL PERSIA.

10. Received from H. B. M.'s Vice-Consul, Resht.

Cotton known as Velayti or local and grown in the Province of Mazanderan.

This cotton was much damaged by the rain. It appeared, however, to consist almost entirely of Type 2

11. Received from H. B. M.'s Vice-Consul, Resht.

Sample of cotton from Irak and supplied under the name of 'Iraki.'

This sample consisted of a *hirsutum* form with fuzzless seed.

12. Received from H. B. M.'s Consul-General, Isphahan.

Cotton from Kashan known as 'Malleh.' Of this cotton it is noted that "it is the most expensive and is very little grown, as this plant produces far less pods than the other kinds, the texture of the cotton being finer and more silky. I am told that no amount of washing or bleaching will change the colour."

The entire series of plants developed from this sample of seed showed the branching characteristic of Type 4 as described above. The lint is khaki in colour.

13. Received from H. B. M.'s Consul-General, Isphahan.

Cotton from Kashan known as 'Shikari.' Of this it was also noted that the cultivation is limited.

This cotton is of Type 3 and possesses a khaki lint.

14. Received from H. B. M.'s Consul-General, Isphahan.

Cotton from Kashan known as 'safed.'

This crop consisted of a large proportion of Type 4 but contained also Type 1.

15. Received from H. B. M.'s Consul-General, Isphahan.

Cotton from Murchikhat. This and the subsequent cotton are reported to be the two best kinds grown in the Province.

The crop proved to consist of Type 5 with a few plants of Type 1.

16. Received from H. B. M.'s Consul-General, Isphahan.

Cotton from Murchikhat.

The plant was the scandent form, Type 7.

17. Received from H. B. M.'s Consul-General, Isphahan.

Cotton from Sultanabad.

The crop consisted of nearly pure Type 1 intermingled with which were a few plants of Types 3 and 5.

18. Received from H. B. M.'s Consul, Sultanabad.

Cotton of the Sultanabad district.

The crop consisted of Type 2.

19—23. Received from H. B. M.'s Vice-Consul, Yezd, through the Consul-General, Isphahan.

Of these samples the following information has been provided.

"The method of cultivation of each kind appears to be identical."

19. "A low bush, short staple, prolific of pods. Cotton known as Kuluzeh.

The plant which is of the *herbaceum* type could not be identified further owing to the damage caused by the rains

20. "Taller (than the last), has to be pinched to stunt it, it is less prolific, but has a longer staple. Known as Vush."

This crop was also badly injured by the rains. It appears to be largely composed of Type 5.

21. "Dirty white seed of similar properties."

"Known as Vush-i-Shikari.

The crop appears to be identical with the last. As, however, no seed set, a comparison of the lint was not possible.

22. "A brownish seed giving brownish wool which is much liked by the village Parsis on account of being the natural colour of their clothing."

"Known as Mahalleh."

Owing to the injury caused by the rains, it was quite impossible to further identify the plant than as of the *herbaceum* type. The lint is of a rich khaki colour.

23. "A tan-coloured seed giving tan-coloured wool, low bush, short staple, small cropper but sought after."

"Known as Surkesh."

This crop also could only be identified as belonging to the *herbaceum* group.

24—27. Received from H. B. M.'s Consul-General, Isphahan.

Cottons grown in the neighbourhood of Isphahan.

24. "Superior quality grown at Khourazgan due East of Isphahan on the road to Yezd."

"Known as Kagazi, *i.e.*, papery."

The crop proved to be pure Type 7.

25. "Superior quality. Grown in the Linjani district, a highly irrigated tract, S.-W. of Isphahan."

"Known as Linjani"

Appears to be pure Type 1 but suffered during the rains.

26. "Medium quality. Grown in the district of Upper and Lower Jarqoyeh, South of Isphahan."

"Known as Par-i-Siyavushi (Adiantum capillus Veneris)."

This does not appear to differ from No. 24, being a distinctly scandent form.

27. "Medium. Grown in the district of Bul khar or Bur khar, North of Isphahan."

"Known as Bul khari or Burkhari."

This is again the scandent form and does not appear to differ from No. 24.

COTTONS FROM NORTH-EAST PERSIA.

28—30. Received from H. B. M.'s Consul, Turbat-i Haidari.

28. The crop consisted of Type 2 intermingled with which were plants of the *hirsutum* form with both fuzzy and fuzzless seeds.

29. Crop similar to the last but without the *hirsutum* form.

30. The crop proved to be nearly pure Type 3.

31—34. Received from H. B. M.'s Consul-General, Khorasan.

31. Cotton from Meshed.

The crop consisted chiefly of Type 5 with a few plants of Type 6. This sample has proved the most resistant of all to the effects of excessive rainfall.

32. Cotton from Meshed.

The crop was a mixture of a larger proportion of the *hirsutum* type with fuzzy seeds, a few fuzzless seeded forms and a few *herbaceum* forms belonging to Type 6.

33. Cotton from Herat.

The crop was a mixture of Types 1 and 3 of which the latter preponderated.

34. Cotton from Herat.

This was found to be pure Type 3.

35—38. Received from H. B. M.'s Consul for Seistan and Kain.

Concerning the cottons Nos. 35—37 H. B. M.'s Vice-Consul, Birjand, writes as follows :—

"Clayey soil is preferable. The ground is prepared just as for wheat. In a climate resembling that of Quetta the seeds are sown about the 10th April."

"For sandy soil, after sowing, the fields should be watered on the 32nd, 48th, 56th and every following 12th day.

"When the plants are about 10 inches high the tops should be broken off.

"Note :—Duroh is situated near the Perso-Afghan frontier, Latitude 30′ 15″, Longitude 60′ 30″."

35. Cotton "grown in Duroh from seed imported from North-West Afghanistan (Herat)."

"4lbs. cotton pods produce 1lb. cleaned cotton."

This appears to be a mixture of Types 2 and 3, the latter preponderating.

36. Cotton "grown in Duroh from seed imported from Western Afghanistan."

"4lbs. cotton pods produce 1lb. clean cotton."

This sample was labelled Coarse Kalakah.

The crop contained Type 5 with a few plants of Type 6.

37. Cotton "grown in Duroh from Persian seed."

"5lbs. cotton pods produce 1lb. cleaned cotton."

This appears to be pure Type 1 but suffered somewhat from wet

38. Cotton grown in Khusf. It is reported to be a very good cotton.

As far as this could be identified, it consisted of Type 5. The crop suffered severely from excessive moisture during the rains.

In response to a wish expressed by some of those who have been kind enough to supply the above samples of seed, a few brief observations on the Persian Cottons are appended. In doing so, it is fully recognised that the observations can only be of a tentative nature. In the absence of any personal acquaintance with the country under consideration it is impossible to speak with any large amount of authority. Though it has been possible, by the growth of these samples, to gather a certain amount of information about the types grown, their behaviour

under the very different conditions which obtain in Persia cannot be estimated. Nevertheless there appear to be certain well defined features which call for comment, and, bearing in mind the limitations imposed, may be detailed here.

As has been noted above, there are two distinct groups of cottons, one of which may be termed the indigenous group. Though composed of various sub-groups or types, these have certain characters in common, a fact which receives recognition in their association under the same specific name, *G. herbaceum.* One of these characters is to be found in the manner in which the fruits ripen. When the boll opens, the segments of the fruit part and the cotton protrudes through the opening thus made. In all the *herbaceum* forms of cotton this opening is slight and the protrusion of cotton consequently small. The cotton is, therefore, with difficulty gathered in a clean state. Usually it is accompanied by a large amount of 'dirt,' consisting of the withered bracts and carpel walls, owing to the presence of which the market value of the cotton is much reduced. The extent of this depreciation and the advantage of clean picking are indicated by the following report on two samples of lint sent by H. B. M.'s Consul for Arabistan and which were kindly valued by the Manager of the Cawnpore Cotton Mills. Both samples belong to cottons of this series.

"A. This is a good cotton, has a fine silky fibre and is fairly even and strong, it will spin successfully 16's to 20's. If it was free from leaf, it would to-day sell at 34/- to 35/- per 100 lbs. at Cawnpore ; its present value is about 32/ to 33/ per 100 lbs."

"B. This is very dirty cotton and has some stained and damaged fibre in it. The spinning qualities of the fibre are fairly good and they are better than Bengals. Counts from 12's to 16's could be spun from it. If the cotton was clean, it would to-day be worth 30/ to 32/ per 100 lbs. in Cawnpore ; in its dirty state it would sell for 23/ to 24/- per 100 lbs."

In the latter case there is, therefore, a depreciation of about 25 per cent. in value due to dirt.

There is, as above shown, a considerable variation in the habit of the different types and, in as much as in a climate with

a short season the yield largely depends on the number of sympodial branches which alone bear fruit, it would appear that certain types are more suitable than others. In this respect Type 2 appears to be the least suitable. Owing to the secondary thickening of the sympodial branches, these are practically infertile. The fertile portion of the plant is therefore limited to the apices of these branches and the tertiaries borne by the branch developed from the accessory bud. Not only, therefore, is the fertile portion of the plant limited, but it is developed after a long vegetative period.

Those types in which a marked development of the accessory bud takes place are also somewhat late in bearing. Owing to the vigour of the accessory shoot, the main sympodial shoots, especially the lower ones, are very reduced and even wither. Little fruit is borne, therefore, until the tertiary branches of the accessory shoot develop.

From the above quoted report it is clear that these types of cottons could be considerably improved by more careful picking. The difficulty is one which is inherent in all forms of *herbaceum* cottons and leads to the question of the possibility of growing kinds which are not of this form. From the above review it is clear that no other form is indigenous to Persia, so that the problem resolves itself into the question of the possibility of importing some foreign cotton. The review of the cottons already found in Persia indicates that a plant of the *hirsutum* type is already well established in the country. It would appear, however, to have undergone a certain amount of "degeneration." The possibility of establishing a plant of this type which will not undergo this degeneration or of establishing the more valuable Egyptian type naturally suggests itself. Indian experience does not give much hope for anticipating success in the former. In the appendix is given for comparison a statement of the rainfall and temperature data for a series of stations in Lower Egypt and Persia. There appears to be a marked similarity between the two countries in this respect. It seems reasonable, therefore, to anticipate the possibility of establishing the cultivation

of the Egyptian type of plant in at least some of the lower tracts of S. W. Persia where irrigation is assured. That this suggestion may not lead to false hopes and subsequent disappointment it is desirable here to draw attention to the difficulties attendant on efforts at acclimatisation ; a subject which has received treatment elsewhere.*

The only definite information received concerning the suitability of the Egyptian cottons is derived from H. B. M.'s Consul-General, Isphahan. On this subject he writes of a conversation with a Parsee that the crop from Egyptian seed which was planted in Rafsenjan, " did not properly ripen owing to the cool weather coming on too quickly for it ; he said they only got 20 *mans* where the ordinary kind would have given 150. The cotton produced was much finer and longer than the ordinary kind and sold for 1 *kran* a *man* more in Bombay, but, on the other hand, ordinary cotton will stand 14—20 days without water, whereas this required it every 7 ; that in the native plant, besides the wool the seeds are good for cattle which will also eat the leaves and stalks, but will not eat the Egyptian."

This attempt appears to have failed, but the district in which it was undertaken differs somewhat from that to which these remarks especially apply.

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* Mem., Dept. Agr., India, Bot. Series, Vol. IV, No. 3.

(2) THE CHINA COTTONS.

THESE cottons are also divisible into two groups, one of which is closely allied to the Asiatic group of cottons, and the other to the Upland or *hirsutum* type of America from which country it would appear that they have been imported. Of the relationship of the former group to the better known Asiatic types found in India it is impossible to speak with certainty at present. The question of this relationship is a matter of the utmost difficulty. There appears to have been no critical study of the Chinese cottons in the field, and such information as is available has been derived from herbarium specimens. By Watt* they have been grouped under the name *G. nanking*, and with them he associates certain forms of Indian cottons among which may be mentioned the Bani or Hinganghat cottons. The forms now under consideration compose a compact group of similar forms characterised by a fully sympodial habit, a leaf-factor < 2, entire bracts and a yellow petal. As far as they have been observed, they appear to fall into 4 types.

Plant, stem and leaves, pubescent, petal yellow with a prominent purple eye, seed fuzzy	Type 1
Plant as in Type 1 but with a khaki lint	„ 2
Plant glabrous, stem, bracts and bolls showing a marked red tinge or 'burning' on their upper exposed side, seed naked	„ 3
Plant similar to Type 3, glabrous, but the red colour found in the vegetative parts of that type entirely absent; petal pure yellow without eye, seed naked ...	„ 4

In the plants of this series there occur two characters which are new to the authors in the Asiatic group of cottons. In both

* *Loc. cit.*

Type 3 and Type 4 the seed is naked and in the latter type the purple eye on the petal is also absent. The group of Asiatic cottons constitutes Watt's Section II, Fuzzy seeded cottons with United Bracteoles, and are characterised by, among other points, the "petals with purple claws." If these Chinese forms, which, in general habit, show a distinct similarity to members of the Asiatic group, are here included, the definition of the group breaks down and the united bracteoles alone remain to characterise the group.

The lint of this series shows considerable variation. Of certain plants it is exceedingly coarse and short, rivalling in this respect that of *G. cernuum*, Tod. Of other plants it is long and to a certain degree silky. In no case has any particular crop been found to be uniform in this respect, and it has, therefore, been impossible to obtain a sufficient sample of lint from the plants with a higher grade staple to obtain a valuation. Some of the best are being carried on as single plant cultures, and from these it is hoped subsequently to get valuations.

The entire series of China cottons have been obtained by the courtesy of the Superintendent, Botanical and Forestry Department, Hong-Kong, and may now be briefly described.

1—4 Received from H. B. M.'s Consul, China. Cottons grown in the Shantung Province.

1. From the Ching Ping district.

This cotton proved to be Type 1 with which were mixed a few plants of the American Type.

2. From the Ko Tong Chan district.

This consisted of Type 1 in a condition of purity.

3. From the Lik Chang district.

This was found to consist of a mixture of Type 1 with a few plants of the American type.

4. From the Shan Kwong district.

The crop appeared to be Type 1 in a condition of purity.

5—7. Cottons grown in the Province of Shanghai.

5. Sample labelled Yellow Cotton.

This crop was found to contain mixture of Types 1 and 2 of which the latter greatly preponderated.

6. Sample labelled White Cotton, First Variety.

The crop was entirely composed of Type 1, the individual plants differing only the quality of fibre and the number of leaf glands.

7. Sample labelled White Cotton, Second Variety.

This was indistinguishable from the last.

8. Received from H. B. M.'s Consul, Nanking, and noted as the variety grown in that district.

It proved to be a mixture of Type 1 with a small proportion of the American Type.

9—11. Cotton grown in the Province of Hankow. Of these it is noted that No. 9 is considered the best, 10 the second, and 11 an inferior variety.

9. The crop proved to be a mixture of Types 1 and 3 with the latter preponderating; a single plant of the American type occurred.

10. This again proved to be a mixture of Types 1 and 3, but in this case there occurred a preponderance of Type 1. A single plant of the American type was found in this sample also.

11. This is Type 1 in a nearly pure condition, a small proportion of Type 3 alone being present.

From the constitution of these three samples it would appear that the quality of the lint in bulk depends directly on the proportion of Type 3 found to occur in the crop. The lint of both Types 1 and 3 shows a considerable range of variation from plant to plant.

12 and 13. Cotton grown in the Tchang Province—

12. The crop was found to contain a mixture of Types 1, 3 and 4 with the addition of the American type. Of these, Types 3 and 4 occurred in about equal proportion with a small addition of the American type, Type 1 being represented by a few stray plants only.

13. The sample bore the following note.

"Said to be foreign seed."

The crop was found to consist of the American type only.

(3) THE SIAM COTTONS.

Among the cottons received from Siam three forms only were found to occur.

(1) *G. purpurascens*, Poir. This is a perennial form known under the name of Bourbon or Porto Rico cotton and the present form differs in no way from plants of this type found in India.

(2) *G. brasiliense*, Macf. The Kidney Cotton. A perennial form, characterised by the fact that the seeds of each cell are united.

(3) The third form is a plant with a fully developed monopodial habit and is cultivable as a perennial. It contains a series of types which appear to be most closely related to, and may be identical with, certain of the cottons grown in Behar and Bengal proper. This group of cottons, which are included in Gammie's group *G. intermedium*, Tod, have, owing to their late habit, not been fully investigated; and the types, of which, as grown in Behar and the East of the U. P., it undoubtedly includes more than one, have not been isolated and grown in pure culture. It is therefore impossible at the present moment to specify this cotton in greater detail.

1. Cotton from the Petrin district.

This sample was composed entirely of *G. purpurascens*, Poir.

2. Cotton from Kampeng district.

This contained the series of monopodial forms above mentioned as allied to *G intermedium*, Tod.

3. Faitade or Common Siam Cotton.

The Kidney Cotton, *G. brasiliense*, Macf.

PLATES.

I. Monopodium and sympodium of approximately equal vigour arising at second node of sympodium.

II. Sympodial branch of *G. cernuum*, Tod. Showing development of accessory bud at first node into a monopodium.

III. A sympodial branch giving monopodia at the second and subsequent nodes.

IV. A complex branch with a weak monopodium developed at second node, and monopodium and sympodium of equal vigour at the third node.

V. A complex branch, the monopodium developed at second node of sympodium of more vigorous growth than the sympodium and giving a series of sympodia from successive nodes.

VI. The accessory bud giving monopodium.

VII. The first node of a sympodial secondary branch from which the accessory bud apparently gives rise to sympodium. The first leaf and terminal bud of the undeveloped monopodium are visible.

PLATE I.

PLATE II.

PLATE III.

PLATE IV.

PLATE V.

PLATE VI.

PLATE VII.

THE MORPHOLOGY AND PARASITISM OF RHIZOCTONIA.

BY

F. J. F. SHAW, B.Sc. (Lond.), A.R.C.S., F.L.S.

THE first reference to *Rhizoctonia* was made by Duhamel(9)*, who, in 1728, described a disease of saffron (*Crocus sativus*). He considered the sclerotia to be a special plant of which the hyphæ were the roots, and named the plant *Tuberoides*. In 1782 Fougeroux de Bondaroy(3) noted that asparagus which grew in the same field as saffron might become infected with this disease. The first attempt, however, to give the fungus a systematic position was made by P. Bulliard(4) who referred it to the Truffles under the name of *Tuber parasiticum*. Shortly afterwards it was placed by Persoon(21) in the genus *Sclerotium* and called *Sclerotium crocorum*. The name *Rhizoctonia* was first used by de Candolle(5) to describe a fungus on lucerne; ultimately he distinguished three species, *R. crocorum*, *R. medicaginis* and *R. mali*. Nees(20) in 1817 also refers to a fungus attacking crocus as *Thanatophytum crocorum*; from an inspection of his figures there can be no doubt that this is *Rhizoctonia*. A few years later Duby(8) discovered *R. allii* or *allium ascalonicum*, and in 1843 Léveillé(18) described *Rhizoctonia* as attacking *Rubia tinctorum*, *Solanum tuberosum*, *Phaseolus*, and other plants; it is not, however, stated to what species of *Rhizoctonia* the attack was due. In 1851 Tulasne(28) united the known forms of *Rhizoctonia* into one species which he called *R. violacea*. This classification has since been adopted by many writers; Saccardo even includes *R. solani* Kühn, in addition to *R. medicaginis* D.C., under *R. violacea* Tul, but in view of the critical work of Kühn a few years later it

* The figures in brackets refer to the bibliography at the end of the paper.

would seem better to maintain the distinction between *R. Solani* and *R. Medicaginis*.

Of the earlier accounts of *Rhizoctonia* the best is that of Kühn(16) published in 1858. He mentions three species of Rhizoctonia—*R. solani*, *R. medicaginis* and *R. crocorum*,—and gives a short account of sclerotial formation on the potato, contrasting the smooth sclerotia of *R. solani* with the woolly sclerotia of *R. medicaginis*; in addition to lucerne *R. medicaginis* is also stated to attack beet and carrot. Kühn describes *Rhizoctonia* as producing a reddish brown colour in the cells of beet; he also gives figures of the hyphæ showing the characteristic mode of branching and the conjugation of cells. This is the first record of the appearance of the fungus in Germany, all the previous attacks having been in France; from now onwards the disease appears to have spread rapidly in Europe. In Denmark, between the years 1886 and 1902, it is recorded on numerous hosts, *e.g.*, carrots, lucerne, clover, sugar-beet and roots of beech, pine and larch. In Sweden the parasitism of the fungus has been recently investigated by Eriksson.(11) His experiments were directed chiefly towards the discovery of biologic forms of the fungus and showed that there was considerable variability in the susceptibility of different varieties of the carrot to the disease. The fungus which attacked the carrot would also attack the beet, though more virulently in the second generation, thus showing an increased adaptation to the new host. In England Güssow(14) has described the disease on potato and lucerne—he considers that *R. solani* and *R. violacea* are one and the same.

In America *Rhizoctonia* is known to attack much the same crops as in Europe. Duggar and Stewart(10) have described it on a number of hosts; they do not, however, give any details about sclerotia, but confine themselves to a description of the vegetative hyphæ, and it is, therefore, impossible to determine from their account whether one or several species of *Rhizoctonia* occurred on the different hosts. The most interesting of the American publications on *Rhizoctonia* is that of Rolfs(24) who describes the morphology and parasitism of a species of *Rhizoctonia* on potato. A fruiting stage

was discovered and stated to be a basidiomycete already known to science as *Corticium vagum B. & C.* A basidiomycete is not, however, the only fruiting stage which has been attributed to *Rhizoctonia.* Fuckel(13) in 1869 stated that the ascomycete *Byssothecium circinans* Fkl. (*Leptosphæria circinans* Sacc.) was the perfect form of *Rhizoctonia ;* both were found on decaying stems of *Medicago sativa*, but beyond this association there was no evidence of their connection with one another. Prunet(23) also observed this association of *Rhizoctonia* on lucerne with an ascomycete, but the absence of details of culture work lessens the value of his statements. Hartig(15) found a fungus resembling *Rhizoctonia* together with a *Rosellinia* on the roots of oak, and it has been suggested by Massee(19) that *Rosellinia* is the fruiting stage of *Rhizoctonia.* In 1897 Frank(12) reported *Rhizoctonia violacea* as attacking grape vines, a *Thelephora* was also found associated with it and named *Th. rhizoctoniæ.* There are, therefore, three or four distinct fungi described as the fruiting stage of *Rhizoctonia* and some doubt still prevails as to which is the true perfect form.

In addition to the usual European hosts it seems fairly certain that *Rhizoctonia* in America attacks seedling cotton. In 1892 Atkinson(1) described a sterile fungus causing a damping off of cotton seedlings, and his description of the hyphæ of this fungus agrees very closely with *Rhizoctonia.* A similar disease known as "Sore shin" has been described in Egypt by Balls(2), who states that it is identical with that described by Atkinson but does not identify it as *Rhizoctonia.* A description of the *Rhizoctonia* attacking cotton in India is given below and a comparison renders it extremely probable that the American, Egyptian and Indian diseases are identical.

In Europe and America *Rhizoctonia* is widely distributed, the following being some of its more important hosts—

Sugar-Beet	*Beta vulgaris.*
Bean	*Phaseolus.*
Carrot	*Daucus carota.*
Cabbage	*Brassica oleracea.*
Cotton	*Gossypium hirsutum*
Lettuce	*Lactuca sativa.*

Potato	*Solanum tuberosum.*
Radish	*Raphanus sativus.*
Sweet Potato	*Ipomœa batatas.*
Pumpkin	*Cucurbita pepo.*
Water Melon	*Citrullus vulgaris.*
Garden Pea	*Pisum sativum.*
Lucerne	*Medicago sativa.*

The fungus frequently attacks the host in the seedling stage, and the similarity to the damping off caused by *Pythium* renders it not improbable that many cases of disease have been wrongly attributed to the latter genus. In India *Rhizoctonia* appears to have a wide range of hosts; in the past year the following plants were attacked on Pusa Farm—

Ground nut	*Arachis hypogœa.*
Cow Pea	*Vigna catiang.*
Jute	*Corchorus capsularis.*
Soy Bean	*Glycine soja.*
Dolichos lablab	
Trichosanthes cucumerina	
Mulberry	*Morus alba.*

It has also been found on ground nut and sesame at Surat, on melon roots at Peshawar, on cotton at Cawnpore and on roots of *Agave rigida* in Madras. Some fifteen years ago Cunningham (7) described a root rot of lucerne and a disease of potato stems known as "Bangle blight," both of which he attributed to the attack of a sclerotial fungus. Judging from his description and figures, the fungus was most probably *R. solani* Kühn, but in his memoir it was not identified. The fact that a disease of potato tubers due to the attack of *R. solani* Kühn is known to occur in Bankipore strengthens this view.

In the rains of 1910 a severe outbreak of the disease took place on Pusa Farm, and the present research was undertaken to discover what species of the fungus was present in India and whether any specialisation existed in its parasitism on different hosts. The association of a basidiomycete resembling *Corticium vagum* with the *Rhizoctonia* also gave a favourable opportunity for investigating the connection between the two. The most important crops attacked were ground nut, cow pea, jute and cotton, and it was

with reference to these four hosts that the existence of physiological races of the fungus was investigated. As it became evident in the course of the research that more than one species of *Rhizoctonia* was present, it will be convenient to consider the results in two parts.

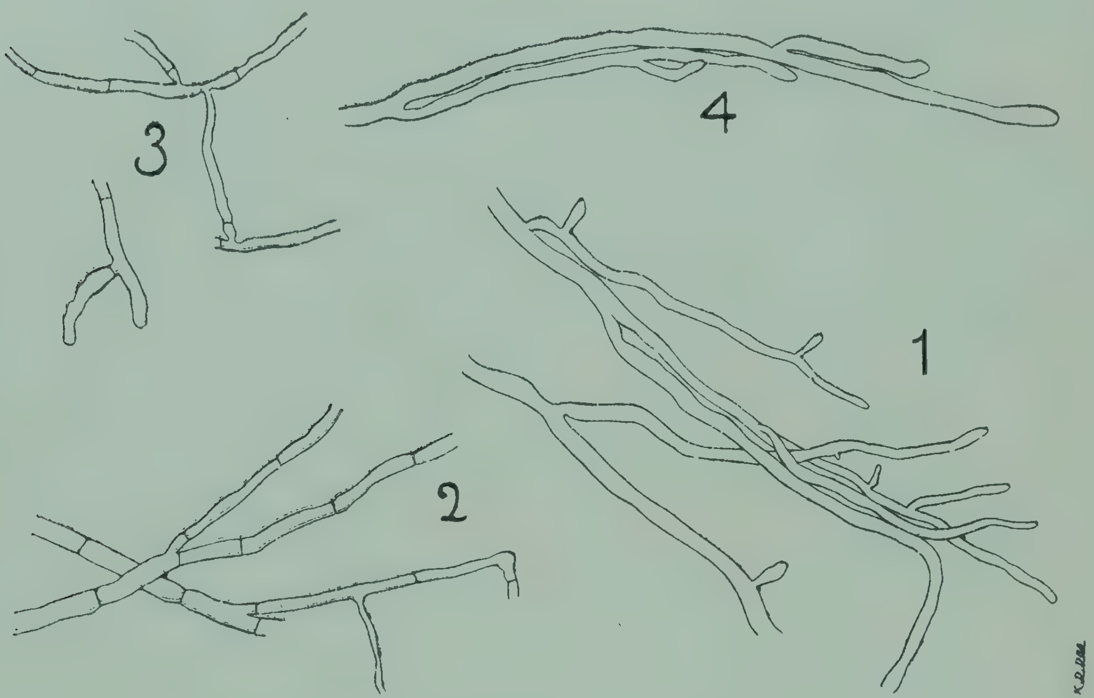
Rhizoctonia solani, Kühn.

Jute.—*Rhizoctonia* has been known for some time as the cause of a destructive disease of seedling jute, the symptoms being very similar to those caused by *Pythium* in other plants. Seedlings attacked by the disease show at first a slight yellowish patch just above the ground level; after a time this darkens and the tissues soften and collapse, the whole seedling falling to the ground (Pl. I, Figs. 3, 4). Young seedlings from one to two inches high are extremely susceptible to the disease.

In some cases plants a good deal older than this were found infected with the fungus. In October 1910, several mature plants in the jute plot at Pusa showed the disease; these plants were from 6 to 8 feet high and could easily be distinguished from their healthy companions by their withered leaves and blackened stems, the blackening being most marked at the base near the ground level. In 1911 the jute was sown on a different area, which had been left fallow during the previous season; there was very little disease in the crop and only a few infected plants could be found. One of these is shown in Pl. I, Fig. 1; the blackened infected area at the base of the stem is clearly visible. In a transverse section through this region the whole of the outer tissues of the stem appear rotted and broken down and in some cases hyphæ can be seen entering the wood (Pl. XI, Fig. 2); sclerotia occur in the decaying cortex. From diseased plants, such as these, cultures were obtained on agar medium E (see Appendix) and produced first a growth of white hyphæ and then numerous small black sclerotia.

In the jute districts of Eastern Bengal *Rhizoctonia* causes a certain amount of damage. Mature plants infected with the fungus have been collected in both the Mymensingh and Rangpur districts. In some years the damage to the seedling crop is extensive in certain

areas. The disease is also known on the Government Farm at Lyallpur in the Punjab and doubtless occurs to a certain extent wherever jute is grown.



TEXT FIG. I.—R. SOLANI KÜHN × 250.

The morphological characters of the fungus appear to vary with the age of the culture. In a sub-culture 24 hours old the hyphæ present the appearance shown in Text Fig. I, 1; the branching is abundant, the young branches are at first bent parallel to the main axis; all show that constriction at the base which is characteristic of *Rhizoctonia;* at this stage transverse walls are very few, the wall which separates a branch from its parent hypha is usually about 15μ from the point of origin of the branch. The hyphæ are about 8—9μ in diameter and the cells from 50—150μ long. In a culture ten days old the upper surface of the agar is covered with a weft of white hyphæ and numerous black sclerotia are embedded in the agar. Under the microscope the aërial hyphæ appear of a blackish colour; they show the characteristic *Rhizoctonia* branching (Text Fig. I, 2), and the larger are from 6—8μ in diameter but the majority are very much finer; the sclerotia when mature appear as dark, black-rounded bodies about 100—150μ in diameter. In old cultures large hyphæ consisting of short barrel-shaped cells are plentiful.

On agar medium D the sclerotia have a brownish colour and are not formed quite so abundantly while on agar medium A; they are much more scattered and the growth is altogether restricted. Cultures on carrot, potato, bread, meal and filter papers all gave sclerotia and hyphæ similar to those on agar; a fruiting stage was never obtained.

The fungus was found to attack seedling jute very vigorously, about 70% of the plants infected being killed. The symptoms and manner of death were as described above. Examination of the diseased seedlings showed hyphæ ramifying in all directions in the tissues of the host; these hyphæ (Text Fig. I, 3) resemble in all respects those in agar culture. By incubating a diseased seedling in a sterile petri dish a growth of white hyphæ was obtained which gave typical sclerotia when subcultured on agar. The vitality of the fungus in culture is considerable, cultures having been found living after five or six months.

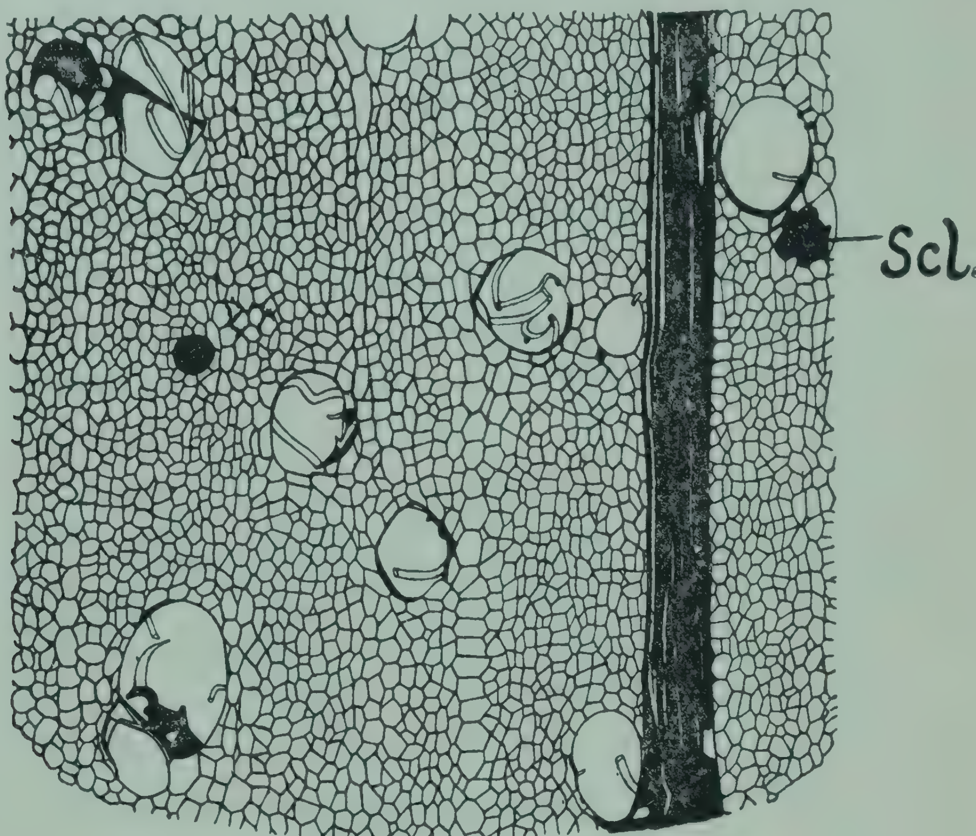
In all the culture experiments the soil was sterilised in steam for three days and placed in pots which had been carefully washed in corrosive sublimate solution. Seeds were washed in formalin solution (2·5%) for ten minutes and then sown, the pots were covered with bell jars as soon as germination took place; unless otherwise stated, infections were made by placing a small piece of agar culture on the stems.

Experiment I.—JUTE.

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	REMARKS.
1	25-2-11	15	..	..	Control.
2	,,	15	7-2-11	12	Plants died in about three days.
3	,,	100	,,	60	Culture spread on top of soil, not laid on plants.

A fungus exactly similar to the *Rhizoctonia* of jute has been found attacking the mulberry, Text Fig. I, 4; shows its appearance in an agar culture 24 hours old. The attack takes place at the base of the plant the whole of the bark and phlœm being destroyed; in

some cases the decayed area completely rings the stem and abundant sclerotia are formed in the wood (Text Fig. II). At this stage the

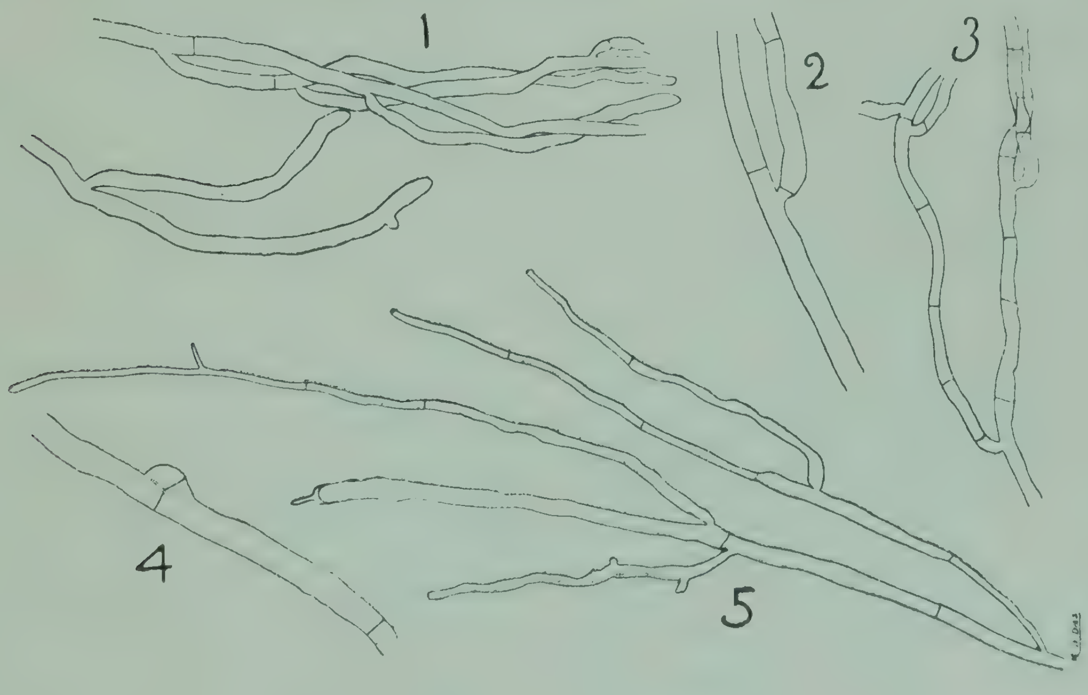


TEXT FIG. II.—R. SOLANI KÜHN.

disease resembles very strongly the "Bangle Blight" of potato (Cunningham (7) Pl. I, Fig. 9, 10). Infections upon jute seedlings gave a mortality of 80% of infected plants; infections upon the mulberry did not give any decisive results. Plants which were infected in July lived until November, when both infected and uninfected plants died owing to the cold weather. Examination of the former, however, showed that the fungus had destroyed the phlœm and was penetrating the wood at the seat of infection.

Cotton.—In June 1911 a disease of cotton occurred on the Cawnpore Farm. Specimens of infected seedlings sent from Cawnpore had a soft yellow patch on the lower portion of the hypocotyl (Pl. IV, Fig. 1), and in bad cases the rot was sufficient to cause collapse of the seedling. Microscopic examination revealed the presence in the rotted area of numerous *Rhizoctonia*-like hyphæ which grew in all directions from the pith to the cortex; sclerotia were not present.

The disease caused some loss among the experimental plants of the Economic Botanist. It was more or less restricted to pot cultures of special varieties and did not attack *desi* cotton in the field. The attack was of brief duration but nearly all the pots showed diseased plants; some of the plants attacked recovered and in this case a dry brown spot persisted on the stem. A second attack on the same plant never takes place. The seedlings seem to be susceptible only when quite young; by the time they are planted out in the field there is no danger of attack; thus deaths were plentiful at the commencement, but ceased after the first few days when seedlings were too old to be attacked. Towards the close of the outbreak several completely withered and diseased seedlings were collected. They all showed hyphæ of *Rhizoctonia* and in one case sclerotia were found on a blackened area at the base of the hypocotyl (cf. Jute seedling, Pl. I, Fig. 1). The sclerotia (Pl. VIII, Fig. 1, Pl. IX, Fig. 2) were rounded bodies, exactly like the sclerotia on jute but rather smaller, the average diameter being about 90μ. The diameter of the hyphæ varied from 6—10μ. Separate cultures were obtained from sclerotia and hyphæ; in both cases the result was a *Rhizoctonia* exactly resembling that on jute. Text Fig. III, 1, shows



TEXT FIG. III.—R. SOLANI KÜHN × 250.

hyphæ in an agar culture 24 hours old and Text Fig. III, 2, 3 represents hyphæ from diseased seedlings. In culture on agar medium E the sclerotia reach a larger size than on the cotton seedlings, some of them being as much as 150μ in diameter.

I have not been able to consult in the original Atkinson's description of the sterile fungus attacking cotton in America, but Balls quotes Atkinson's description as follows :—

"The freshly developed threads branch freely, but not profusely ; they are colourless, composed of elongated cells 9—11μ in diameter, and 100—200μ in length. The branches very near the point of attachment are a little curved towards the point of growth of the same. At the point of attachment with the parent hypha, the branch is considerably smaller than either the diameter of the parent hyphæ or the main part of the branch, and the septum separating the protoplasm of the greater part of the branch from that of the parent hypha, is situated some distance from the latter, usually 15—20μ from the main thread. This portion of the branch, the contents of which are continuous with the parent thread, is clavate in form."

Other American authors evidently consider this disease to be due to *Rhizoctonia* ; thus Duggar and Stewart (10) include it in their paper under the heading "*Rhizoctonia* in America," and Stevens and Hall(27) give "rhizoctoniose" as a synonym for "sore shin." A comparison of the above description with that of the fungus which has just been described as attacking jute and cotton shows a substantial agreement in all essential points. Atkinson's measurements seem to be slightly larger, but it has already been mentioned that the size of the hyphæ varies with the age of the culture.

Balls states that Atkinson's description applies equally well to the Egyptian "sore shin" fungus ; it follows therefore that in America, Egypt and India cotton is attacked by *Rhizoctonia.* The symptoms of "sore shin" disease agree exactly with those of the present outbreak, but Balls did not obtain any of the sclerotia which occur so abundantly in our cultures and which are mentioned by Atkinson. The only reproductive organs which he mentions are termed "resting cells," and are stated to arise by the enlargement

of certain hyphæ which become segmented into barrel-shaped cells. Hyphæ such as these occur in our cultures but are nearly always an early stage in the formation of a sclerotium (Pl. VII, Figs. 1, 2, 3); in some cases similar hyphæ are plentiful in older cultures.

According to Balls(2) a medium consisting of filter papers in 2% solution of asparagin or cane-sugar is most suitable for the formation of "resting cells." Cultures of the *Rhizoctonia* of ground nut on filter paper moistened with a solution of lactic acid and nutrient salts (see Appendix) gave rise to hyphæ with sclerotia consisting of large loosely connected cells (Pl. VIII, Figs. 2, 3). In cultures of the *Rhizoctonia* of cotton on filter paper moistened with 2% cane-sugar or asparagin similar structures were formed.

Inoculations in the laboratory gave different results according to the variety of cotton infected. While *Rhizoctonia* does not attack *desi* cotton in the field, it caused a mortality of 20—30% in the experiment detailed below. In the case of another variety of cotton known as "khaki" the mortality reached as high as 90 per cent.

Experiment II.—"DESI" SEED.

Pot.	Date of sowing	No. of plants in pot.	Date of infection.	Deaths.	REMARKS.
1	1-7-11	5	..	..	Control.
2	,,	3	6-7-11	..	....
3	,,	3	,,	..	....
4	,,	3	,,	2	Plants died 14 days after infection.
5	4-7-11	6	9-7-11	..	Infected with young culture.
6	,,	5	,,	2	
7	,,	5	,,	1	Infected with old culture.
8	,,	5	,,	2	

Experiment III.—"KHAKI" SEED.

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	REMARKS.
9	11-7-11	6	17-7-11	5	Isolated *Rhizoctonia* from one of the diseased plants.
10	,,	3	,,	..	Control.
11	,,	4	,,	..	
12	,,	2	,,	..	

Ground nut.—In the beginning of 1911, while examining some seeds of ground nut, it was noticed that in a large number of seeds the pericarp had a mottled appearance, showing discoloured patches (Pl. IV, Figs. 3, 4). Examination of these dark areas revealed, in some cases, hyphæ, like those of *Rhizoctonia*, ramifying in the tissues; in other cases there was no apparent cause for the discoloration. Not only were hyphæ found in the pericarp but they were also sometimes present within the embryo. Portions of the pericarp of seeds, and, in some cases, entire seeds, were incubated in sterile petri dishes and gave a vigorous growth of hyphæ of *Rhizoctonia* which was sub-cultured on agar medium E.

A further experiment was then performed in which four seeds were sterilised by soaking in 2·5% Formalin for five minutes, and sown in sterile drying towers containing Knop's solution, a method first used by Ward(29). Of these four seeds only one germinated, the remaining three died and became covered with an abundant growth of hyphæ and small black sclerotia, which were sub-cultured on agar medium E; the cultures obtained in this way resembled those of the *Rhizoctonia* of cotton and jute. Later in the year, in August, an examination of the ground nut crop on Pusa Farm showed that many plants were infected with *Rhizoctonia*. The upper portion of infected plants appears brown and withered (Pl. III, Fig. 3), while at the ground level the stem is a dark black colour; in this portion hyphæ and sclerotia are particularly abundant. Specimens of ground nut attacked by *Rhizoctonia* were also received from Surat; in these the small black sclerotia were abundant, occurring not only on stems but also on leaves. A small piece of one of these blackened stems was incubated and gave a culture which resembled in all respects that obtained from the hyphæ in the seeds. In this connection it may be noted here that specimens of diseased sesame from Surat were found to be infected with *Rhizoctonia* in the same way as the ground nut, the external symptoms of the disease and the cultural characters of the fungus exactly resembling those detailed above.

Further proof that the ground nut seed may be infected with *Rhizoctonia* was afforded by the behaviour of the plant in pot culture. Out of all the cultures of the jute, cotton, cow pea and ground nut made in the course of this research, it was only in the case of ground nut that deaths due to *Rhizoctonia* infection took place in the control pots. If the deaths in the control pots had been due to soil infection, owing to imperfect sterilisation, it would be expected that similar deaths would also take place in the cultures of jute, which is far more susceptible to the attack of *Rhizoctonia* than is ground nut. Moreover, the ground nut ripens its seeds below the surface of the ground in the same situation as those tubers (potato, carrot, etc.) which are often badly attacked by *Rhizoctonia*.

The morphological features of the *Rhizoctonia* of ground nut agree exactly with those of cotton and jute. The characteristics of the hyphæ in an agar culture 24 hours old are shown in Text Fig. III, 5 ; in the case of some diseased plants from Peshawar hyphæ with clamp connections were present (Text Fig. III, 4). The manner of the formation of the sclerotia was studied and is shown in Pl. VII, Figs. 1, 2, 3, & 4. In a hypha which is about to form a sclerotium a large number of transverse divisions take place, so that a number of short barrel-shaped cells are formed which are very rich in oil globules. Some of these give rise to lateral outgrowths, consisting of one or two cells, which grow parallel with, and adhere to, the side of the parent hypha. By the constant repetition of this process a mass of parenchymatous cells is formed which eventually becomes the mature sclerotium (Pl. IX, Figs. 1, 2) ; there is some slight differentiation into cortex and medulla, the central cells being large and thin-walled, while the peripheral cells have a smaller lumen and thicker walls. This process agrees closely with that described by Kühn for sclerotial formation in *R. solani*.

Culture work on the ground nut was complicated by the liability to sow infected seed. On the whole, about 30% of the inoculations were successful. In a successful inoculation the stem turns

brown at the point of infection and numerous black sclerotia are formed. If the ground nut were first wounded, the percentage of deaths reached as high as fifty ; this plant also seemed peculiarly susceptible to attack at the growing point.

Experiment IV.—GROUND NUT (PUSA SEED).

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	REMARKS.
1	17-5-11	5	..	..	Control.
2	,,	4	27-5-11	1	Plants become rotted at point of infection just above ground level, abundant hyphæ and sclerotia formed.
3	,,	4	Wounded & infected. 29-5-11	1	
4	,,	5	25-5-11	2	..
5	,,	4	Wounded & infected. 12-6-11	1	Infected near growing point.
6	,,	6	12-6-11	2	

Cow pea.—The symptoms of attack in this case are the same as those already described for the ground nut, and the fungus also resembles that of the other three hosts (Pl. IX, Fig. 1). Inoculations upon the cow pea produce abundant sclerotia (Pl. II, Fig. 3) ; as in the ground nut, the growing point seems peculiarly liable to infection. In the early stages of infection a red brown discoloration appears upon the stem and slowly spreads, the stem ultimately becomes flaccid and collapses. Sclerotia are formed abundantly. A portion of a diseased stem was incubated and gave a vigorous growth of *Rhizoctonia*. Infections from agar cultures on unwounded plants gave an average mortality of 50% ; if the plants had been previously wounded at the point of infection the mortality sometimes reached as high as 80% of the infections. In one pot the plants were infected with a piece of a diseased plant from another pot, and it was noticeable that in this case the virulence of the fungus seemed to be less than in the previous experiments, only one infection out of six proving fatal.

Experiment V.—Cow pea (Pusa seed).

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	Remarks.
1	8-3-11	7	17-3-11	3	Infection usually shows sign of taking after 4 or 7 days, but sometimes death not complete for 6 weeks.
2	,,	3	20-3-11	2	....
3	,,	6	Wounded & infected 25-3-11	3	In one plant which was infected at the base—the hyphæ grew right up in the stem and formed abundant sclerotia on the growing point.
4	,,	5	Wounded & infected 25-3-11	4	....
5	17-5-11	6	11-6-11	4	Infection with culture from Cow pea seeds not agar.
6	17-5-11	6	29-5-11	1	Infected with piece of stem containing sclerotia from dead plant of pot 2.
7	8-3-11	7	..	..	Control.

Cross inoculations.

Eriksson(11) investigated the parasitism of *Rhizoctonia* on carrots, beet-root and other European hosts, and found that the susceptibility of carrot to the attack of *Rhizoctonia* varied according to the variety of carrot infected. He was able to make the *Rhizoctonia* pass from the carrot to the beet. Its virulence upon beet, however, was greatly increased after being parasitic upon that plant for one generation, thus showing a gradual adaptation to the new host; clover, which is sometimes attacked in Denmark, he was not able to infect with this *Rhizoctonia*. Eriksson's results show therefore a very slight specialisation in the parasitism on different hosts.

In the case of the four crops dealt with in this research the results agree more or less with those of Eriksson. In three of the hosts, namely, ground nut, cotton and cow pea the infection powers of the respective *Rhizoctonias* seem to be of a like order. In each case the fungus isolated from any one host will infect the other two;

although its virulence is greatest on its own particular host. Thus the *Rhizoctonia* from cotton if infected upon ground nut, jute or cow pea has a mortality of about 40—50%, but upon cotton it has a mortality of 80%.

The behaviour of the jute plant and its *Rhizoctonia* is, however, rather different. Jute is attacked very vigorously by its own *Rhizoctonia*, the mortality rarely falling below 70% of infected plants. *Rhizoctonia* of cotton and ground nut is considerably less virulent on jute, the infective power of the latter being much higher if the jute be first wounded. This applies in an even greater degree to the *Rhizoctonia* of cow pea, which does not attack uninjured jute at all but has a mortality of 50% on wounded jute.

The *Rhizoctonia* of jute shows a high degree of specialisation as it does not, under normal circumstances, attack the other three hosts at all. Both on *desi* and "khaki" cotton and wounded and unwounded cow pea infections failed to take. In the latter plant the host successfully reacted to the attack by cork formation round the infected area (Pl. VI, Fig. 2); in cotton the hyphæ seemed unable to penetrate the epidermis and the plant was not injured in any way. In the early stages of attack on the cow pea the hyphæ are more or less intercellular in growth. In those cases in which the plant reacts successfully against the fungus (*e.g.*, attack of the *Rhizoctonia* of jute) the hyphæ appear to remain in this state (Pl. VI, Fig. 2) : should, however, the *Rhizoctonia* prove fatal, intracellular hyphæ are speedily formed (Pl. VI, Fig. 1).

Infections which were made on ground nut early in the year failed to give any result, but on repeating the experiment four months later death resulted in the case of one infection. The ground nut seed in this case, however, was not above suspicion ; at the same time the fact must not be overlooked that after nearly a year in culture the infective powers of a fungus may change. On the whole, considering all the facts with regard to the *Rhizoctonia* of jute, it seems clear that we have to do here with a physiological specialisation unaccompanied by any outward morphological distinction. Details of the experimental work are shown opposite on page :

Experiment VI.—Rhizoctonia of jute on cow pea—

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	REMARKS.
1	17-2-11	6	..	..	Control.
2	„	6	Wound infection 28-2-11	..	Plant reacted against attack of fungus by cork formation.
3	29-5-11	8	..	..	Control.
4	„	5	5-6-11	..	No trace of infection after 5 weeks.
5	8-3-11	7	21-3-11	..	....

Experiment VII.—Rhizoctonia of jute on cotton (*desi* seed). In this experiment the seed was germinated on moist blotting paper in petri dishes and afterwards planted—

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	REMARKS.
1	20-8-11	6	..	..	Control.
2	„	6	..	..	„
3	„	7	25-8-11	..	No attack.
1	2-6-11	6	..	..	Control.
2	„	5	6-6-11	..	No attack.

Experiment VIII.—Rhizoctonia of jute on cotton ("khaki" seed). The seed was germinated in petri dishes as in Exp. VII—

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	REMARKS.
1	16-8-11	6	..	1 (?)	Control.
2	„	5	25-8-11	3 (?)	All the deaths were due to attack by *Fusarium*.
3	„	3	..	..	Control.

Pot.	Date of sowings.	No. of plants in pot.	Date of infection.	Deaths.	REMARKS.
1	16-9-11	5	21-9-11	..	Infection did not take.
2	„	6	„	..	„
3	„	4	..	..	Control—one death due to *Fusarium*.
4	„	4	..	1 (?)	
5	„	3	..	..	

Experiment IX.—Infection of *Rhizoctonia* of jute on ground nut—

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	REMARKS.
1	6-3-11	6	..	..	Control.
2	,,	6	21-3-11 3 Wound infections 3 Infections without wounds	.. ..	.. ..
3	27-7-11	7	Infected hypocotyl and root 7-8-11	2—3	..
4	,,	6	Wounded & infected hypocotyl & root 7-8-11	1—3	..
5	,,	4	..	3	Control.
6	,,	5	..	1	

In the case of the plants in Pot 3 it is very probable that the deaths were due to infected seed. All the diseased plants developed *Rhizoctonia* in the root at the seat of infection, but one also showed a copious growth of *Rhizoctonia* at the apex where there had been no infection; the intermediate portion of the stem was quite healthy and did not contain any hyphæ. In Pot 4 only one plant developed *Rhizoctonia* at the seat of infection, the other two plants developed it at the apex. In the control pots two of the deaths in Pot 5 were due to the development of *Rhizoctonia* at the apex, and one to an attack at the base of the hypocotyl; the death in Pot 6 was also due to an attack at the base of the hypocotyl.

Experiment X.—*Rhizoctonia* of cotton on jute—

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	REMARKS.
1	25-7-11	8	..	..	Control.
2	,,	8	..	..	..
3	,,	11	3-7-11	2	Deaths took place from 2 to 7 days after infection.
4	,,	8	,,	6	Incubation of diseased plant gave *Rhizoctonia*.

Experiment XI.—*Rhizoctonia* of cotton on cow pea—

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	Remarks.
1	11-7-11	5	17-7-11	4	....
2	,,	6	..	..	Control.
3	5-8-11	1	..	..	
4	,,	2	..	..	
5	,,	1	..	..	
6	,,	4	Wounded and infected 10-8-11	2	....

Sclerotia were not formed so abundantly on diseased plants as in other cases. The stems became reddish brown and soft at the point of attack. hyphæ were numerous running in all directions through the cells. Infections were made both at the growing point and on the hypocotyl; in one of the former sclerotia were formed (Pl. IV, Fig. 2).

Experiment XII.—*Rhizoctonia* of cotton on ground nut (small Japan)—

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	Remarks.
1	20-6-11	6	..	..	Control.
2	,,	6	3-7-11	1	Infection made at the apex, which became covered with sclerotia, none of the ground level infections took.
3	,,	6	,,	..	
4	,,	6	,,	..	
5	27-7-11	6	Infected stem & root 7-8-11	2	..
6	,,	4	Wounded and infected stem & root 7-8-11	4	..
7	,,	4	..	2	Control.
8	,,	5	..	1	

In Pot V the plants developed *Rhizoctonia* at the apex and not at the base, where they had been infected. In three of the plants in Pot 6 the *Rhizoctonia* was developed at the place of infection, the whole of the hypocotyl becoming rotted with abundant formation

of sclerotia ; in the remaining plant the apex became attacked. The diseased plants in the control pots were attacked both at the apex and the base. It is impossible to say whether all the cases of death were due to infected seed, the three deaths in Pot 6 may be due to *Rhizoctonia* of cotton. At all events it appears from Pot 2 that *Rhizoctonia* of cotton can attack ground nut.

Experiment XIII.—Rhizoctonia of ground nut on jute—

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	REMARKS.
1	17-5-11	8	23-5-11	6	Wounded & infected.
2	,,	14	,,	3	Infected without wound.
3	,,	8	,,	..	Wounded not infected.
4	,,	8	..	..	Control.

Experiment XIV.—Rhizoctonia of ground nut on cotton (*desi* seed)—

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	REMARKS.
1	2-6-11	6	..	..	Control.
2	,,	6	5-6-11	..	Sclerotia and hyphæ developed, obtained pure culture on incubating diseased plants, 4-7-11.
3	,,	6	,,	2	
4	16-6-11	4	..	..	Wounded not infected.
5	,,	6	20-6-11	1	Wounded and infected. One death due to *Rhizoctonia*.
6	20-8-11	6	..	..	Control.
7	,,	6	..	..	
8	,,	6	25-8-11	..	

Experiment XV.—Rhizoctonia of ground nut on cotton ("khaki" seed)—

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	REMARKS.
1	16-8-11	6	..	..	Control.
2	,,	6	25-8-11	..	Infection did not take.
3	,,	3	..	..	Control.

Rhizoctonia of ground nut is slightly parasitic on cotton.

Experiment XVI.—Rhizoctonia of ground nut on cow pea—

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	Remarks.
1	17-5-11	7	23-5-11	3	Sclerotia formed abundantly, incubated diseased plants and obtained culture of *Rhizoctonia.*
2	,,	8	23-5-11	3	
3	,,	6	..	..	Control.
4	29-5-11	8	..	..	Control.
5	,,	6	5-6-11	..	

Infections take more readily at the apex than at the base.

Experiment XVII.—Rhizoctonia of cow pea on jute—

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	Remarks.
1	25-2-11	9	17-3-11	..	Infected without wounding.
2	,,	9	,,	4	Wounded and infected.
3	,,	9	..	..	Control.

Experiment XVIII.—Rhizoctonia of cow pea on cotton ("khaki")—

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	Remarks.
1	1-8-11	4	8-8-11	3	Incubated diseased plants and obtained culture of *Rhizoctonia.*
2	,,	1	Wounded and infected, 8-8-11	1	Incubated diseased plants and obtained culture of *Rhizoctonia.*
3	,,	4	..	..	Control.
4	,,	2	..	..	Wounded not infected.
5	,,	4	Wounded and infected, 10-8-11	2	

Experiment XIX.—Rhizoctonia of cow pea on ground nut—

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	REMARKS.
1	6-3-11	6	..	1	Control pot not kept under a bell jar—one death due to *Rhizoctonia.*
2	,,	6	..	..	
3	,,	6	28-3-11	..	
4	,,	6	Wounded and infected, 27-3-11	2	*Rhizoctonia* developed in tissues at point of infection.

It is difficult to be certain from the results of this experiment whether the *Rhizoctonia* of cow pea is really parasitic on ground nut. In a further experiment the seeds were germinated under conditions, which rendered chance infection practically impossible ; under these circumstances the appearance of the disease could only result from deliberate inoculation or from the use of infected seed. Five carefully selected seeds were sown on cotton-wool in sterile drying towers containing Knop's solution ; all the seeds germinated, but only three produced healthy young seedlings. One of these was inoculated at the apex and also just below the cotyledon with *Rhizoctonia* of cow pea. This plant very soon died with an abundant development of *Rhizoctonia* in the infected areas (Pl. III, Fig. 1).

The following table shows at a glance the infective powers of the different varieties of *Rhizoctonia*, the numbers refer to the percentage of inoculations which proved fatal—

GROUND NUT.		JUTE.	COW PEA.	COTTON.		REMARKS.
Pusa seed.	Small Japan.	14—72	42	Desi.	Khaki.	*Rhizoctonia of ground nut.*
30	..	..	..	16	No result.	
16	5	50 Inoculations failed to take unless the plant was first wounded.	50—80	..	60—70	*Rhizoctonia of cow pea.*
..	16	40	50—80	20—30	90	*Rhizoctonia of cotton.*
No result.		60—80	No result.		No result.	*Rhizoctonia of jute.*

In cases where the figures show a wide variation in the mortality the higher number refers to inoculations made upon plants which had been first wounded.

The variety of ground nut referred to as "small Japan" was obtained from Bombay in the hope of getting seed free from infection.

Preventive measures.

Rhizoctonia is essentially a soil fungus attacking the subterranean portions of plants and passing over unfavourable periods by means of its sclerotia. Any method of treating the disease should have therefore as its first objective the destruction of the sclerotia in the soil. To do this on a large scale is an operation of some difficulty and expense, and is not a proceeding which is likely to commend itself to the Indian cultivator. Probably the best means of combating the disease is by a careful rotation of crops; up to the present there does not appear to be any record of *Rhizoctonia* attacking a cereal crop, and such crops might be grown with safety in fields, where more susceptible plants would be destroyed. It is not exactly known how long the fungus can perennate in the soil. Prunet (23) mentions three years as the time during which a field might remain infectious.

In the case of cotton Balls (2) has found a seed-dressing of naphthaline beneficial in the treatment of the disease. If used in the right proportion the vapour of naphthaline does not injure the germination and is sufficient to kill or inhibit the growth of the fungus during the early stages when the seedling is liable to attack.

Eriksson's experiments indicated that treatment of the soil with carbolic acid might be a preventive for the disease and further work by Salmon (25) has confirmed this. The solution used was 1 oz. of phenol to 1 gallon of water, and about 40 gallons were applied by means of a watering pot to a plot of land 19 feet by 9 feet.

Some experiments made in Pusa seem to show that carbolic powder is capable of protecting jute from the attack of *Rhizoctonia*; careful research is, however, necessary in order that the germination of the seed may not be injured by the disinfectant—

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Remarks.
1	14-8-11	15	Soil not infected with Rhizoctonia.	7 seeds germinated and formed healthy plants.
2 soil treated with carbolic ..	"	"		11 do. do. do.
3 soil treated with naphthaline ..	"	"	..	No germination.
4	"	"	..	11 seeds germinated, all seedlings killed.
5 soil treated with carbolic ..	"	"	Fungus spread in soil with seed.	7 seeds germinated and formed healthy plants.
6 soil treated with naphthaline ..	"	"	..	No germination.

From the above table it will be seen that jute seed is very sensitive to naphthaline. Methods, such as this, which aim at destroying the fungus in the soil, must be distinguished from others, which merely ensure the planting of clean seeds. In the case of tubers (*e.g.*, potato), and plants (*e.g.*, ground nut) which ripen their seed below the ground level, some means of disinfecting diseased seed should be adopted. Rolfs (24) found that treatment of diseased potato seed with corrosive sublimate or formalin considerably improved the outturn; this method, however, must be combined with suitable and systematic rotation in order to give the best results.

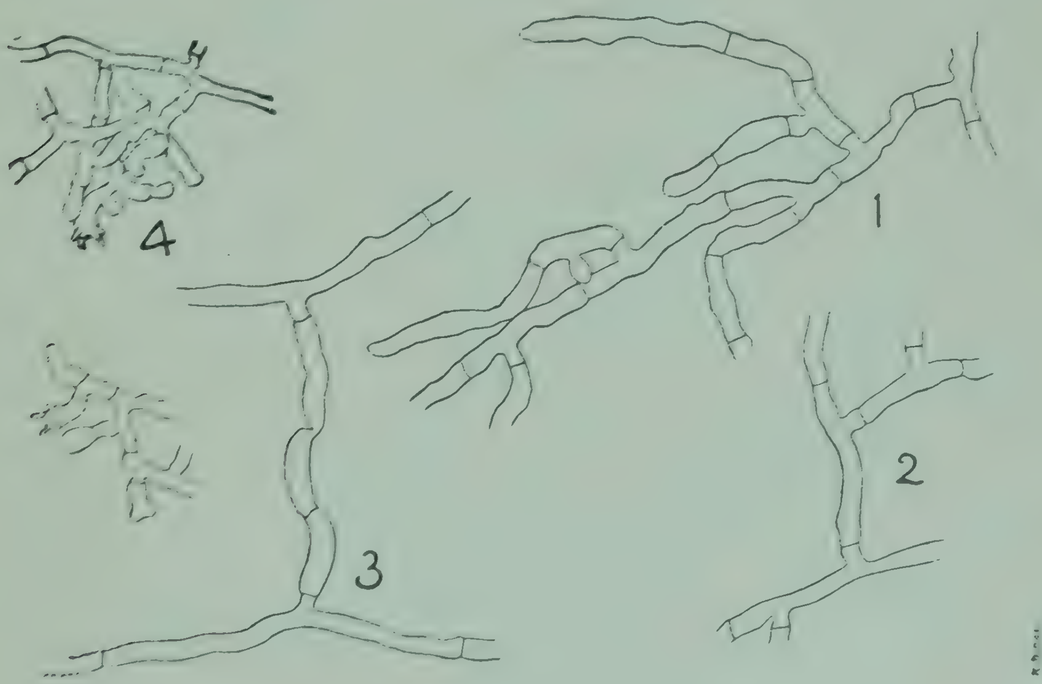
Identity of the fungus.

The commonest species of *Rhizoctonia* appears to be *R. violacea* Tul., under which name Saccardo includes *R. Medicaginis* D. C. and *R. Solani* Kühn. Kühn gives a careful description of these two forms and states that the principal difference between them lies in the sclerotium; in both cases this is a small round black structure, but that of *R. Solani* is smooth while that of *R. Medicaginis* is covered with hyphæ. A comparison of Fig. 1, Pl. IX, in this paper with Taf. VII, Fig. 21 of Kühn shows the essential similarity between the sclerotium of *R. Solani* and that of the form described above; moreover, the sclerotial fungus which occurs on potato

tubers at Bankipore is morphologically indistinguishable from that which has just been described on jute, cotton, ground nut and cow pea. Under these circumstances it seems better to identify the *Rhizoctonia* which attacks these four crops as *R. Solani* Kühn than either as *R. Medicaginis* D. C., or the rather indefinite *R. violaceæ* Tul. It may be noted here that Eriksson refers to the *Rhizoctonia* on carrot as *R. violacea*, and in his figures the sclerotia appear as small black dots like those on the cow pea (Pl. II, Fig. 3); *R. Medicaginis* is, however, described as attacking the carrot and Eriksson's fungus was probably this. It is impossible to tell from the description of Cunningham (7) whether the sclerotial fungus which he describes as attacking lucerne in India was *R. Solani* or *R. Medicaginis*.

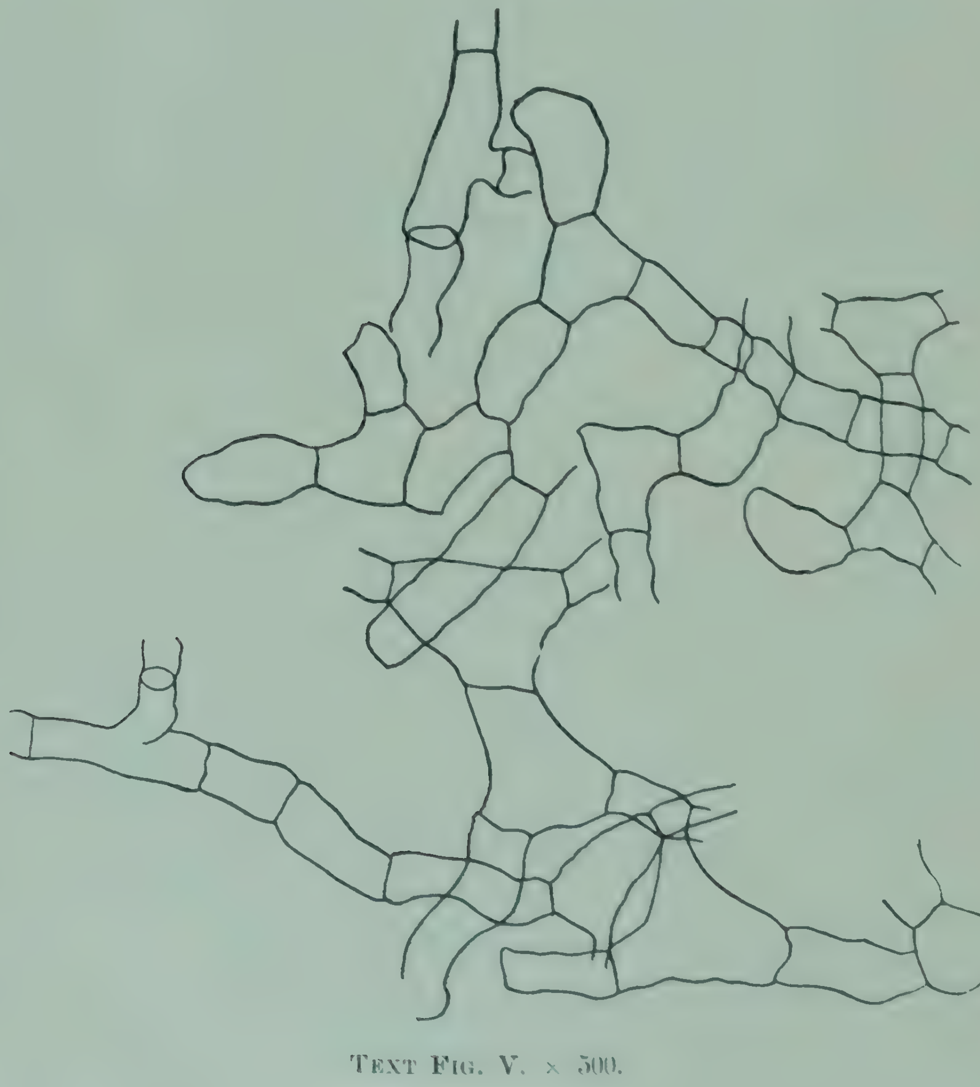
Corticium vagum B. & C.

In October and November 1910, and also in 1911, a form of *Rhizoctonia* which differed considerably from the above was found attacking the ground nut and cow pea. Diseased plants were brown and withered at the infected spots, and usually bore several sclerotia, which were much larger than the sclerotia of *R. Solani*, the size varying from 1-5 mm. (Pl. V, Figs. 1, 2).



Text Fig. IV Corticium Vagum B. & C. × 250.

The hyphæ of the fungus to which these sclerotia belong resembled strongly those of the *R. Solani* attacking jute, cotton, &c. The cells were from 6-10μ in diameter and from 100-200μ long, the branches all showed the basal constriction and disposition of the transverse wall which is characteristic of *Rhizoctonia* (Text Fig. IV. 1); conjugation between cells of different hyphæ sometimes takes place (Text Fig. IV. 3). There was some variation in the size of the cells, but not so much as in the case of the *Rhizoctonia* of jute. The very fine hyphæ which occur in cultures of the latter are not present here; in old cultures the hyphæ turn a reddish brown colour. Mature hyphæ often present the curious appearance shown in (Text Fig. V), the cells being of triangular shape; this is usually an early stage in the formation of a sclerotium (cf. Rolfs Pl. V, Fig. 2, Bull. 91). Young sclerotia are visible to the naked eye as fluffy aggrega-



TEXT FIG. V. × 500.

tions of hyphæ. They are at first quite white, but later the colour changes to brown, and they become hard and compact. The mature sclerotium is very different to that of *R. Solani* Kühn. It can easily be seen that it consists of interwoven hyphæ (Fig. 1, Pl. XI), the structure is uniform throughout, and there is complete absence of any differentiation into cortex and medulla. These large sclerotia are much more obviously composed of pseudo-parenchyma than are the small ones of *R. Solani.*

In some diseased ground nut plants certain leaves were coated on the surface with a white layer (Pl. V, Fig. 3). Examination of this layer showed it to be composed of closely interwoven hyphæ. which were obviously *Rhizoctonia* hyphæ. In some parts of the leaf, where this layer was most marked. the lateral branches of the hyphæ were very numerous and peculiar. These branches were short club-shaped structures with a transverse wall some distance from the point of origin, their swollen club-shaped ends often bore from two to four finger-like processes, each of which carried a single spore : they were in fact basidia bearing four sterigmata (Text Fig. IV, 4). The spores are hyaline oval structures about 12-10 by 8-6μ (Pl. X, Figs. 3, 4, 5). This form of fructification was found on the cow pea (Pl. V, Fig. 4,), and on *Trichosanthes*, in addition to the ground nut ; on all three plants hyphæ and sclerotia of the type just described were present. Hyphæ are abundant in the tissues of leaves which bear the basidial layer. Infections upon cow pea and ground nut showed that the fungus was a virulent parasite upon both these plants. Seedlings of cow pea were infected both near the growing point and on the hypocotyl, the former taking the more vigorously. The infected area rapidly turns a reddish brown colour, as described in the case of *R. Solani*, and the tissue becomes soft, the whole plant finally collapsing (Pl. IV, Fig. 5).

In the case of the ground nut, mature plants, bearing nuts, were taken from the field and placed in pots. Infections upon the leaves gave rise, at first, to a white growth of hyphæ, which formed later both sclerotia and the characteristic fruiting layer. Hyphæ subsequently spread all over the plant, which gradually turned a

deep brown colour; death was slow in the case of a mature plant of ground nut. The infections were made in each case with hyphæ from an agar culture which had been originally infected with a sclerotium; this sclerotium was obtained from a culture made by infecting an agar tube with a scraping of basidia. The connection between basidia and sclerotia is, therefore, established.

Infection on the cow pea—

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	REMARKS.
I	19-10-11	4	..	..	Control.
II	"	3	27-10-11	3	*Rhizoctonia* hyphæ abundant in diseased tissue.

Infection on the ground nut.—

Pot.	Date of sowing.	No. of plants in pot.	Date of infection.	Deaths.	REMARKS.
I	Taken from field and potted 24-10-11	1	..	..	Control.
II					
III		1	..	..	
IV		1	30-10-11	2	Sclerotia and basidia formed on plants.
		1			

It was found to be impossible to get the perfect stage into culture on artificial media. It is apparently strictly parasitic. On the living plant it forms a close network on the surface of stem and leaves, and when the spores have been shed it wears off. In the field the development of basidia is particularly vigorous on those leaves which are well shaded and in moist damp situations.

Cultures on agar (media B, C, D, E, F, G), all produced abundant white hyphæ and sclerotia. This happened both in the case of tubes infected with sclerotia and in those infected with a scraping from the fertile layer. Cultures upon filter paper, pith moistened with extract of ground nuts and corn meal also gave the same results.

In addition to the evidence from inoculations other facts all go to prove that the perfect form of *Rhizoctonia* is a basidiomycete such as we have described.

In the first place, this basidiomycete has been associated with the same sclerotia and hyphæ for two successive years on three different hosts, and moreover it agrees in every particular with that described by Rolfs as attacking potatoes in America; Rolfs identifies it as *Corticium vagum* B. & C. The evidence which he gives for regarding it as the fertile stage of *Rhizoctonia* is—

(1) association of basidia and sclerotia on same host;

(2) cultures obtained by germinating spores on agar had the typical characteristics of *Rhizoctonia;*

(3) infection of sclerotia and *Rhizoctonia* hyphæ on living plants gave rise to the fruiting layer.

Rolf's description of the sclerotia and hyphæ which are connected with the *Corticium* stage agrees in all essentials with that given above (cf. Rolfs' Bull. 91, Pl. I and Pl. V with Pl. V, Fig. 3 and Text Fig. V), and does not resemble the *R. Solani* Kühn described in the earlier portion of this memoir.

Further evidence of the organic connection between these sclerotia and hyphæ and the basidiomycete is furnished by a paper by Stevens and Hall (26) entitled "Hypochnose of Pomaceous Fruits." These authors describe a fungus, attacking apple, pear and quince, which has all the characteristics of *Rhizoctonia.* The hyphæ have the typical *Rhizoctonia* appearance (Fig. 5, Stevens and Hall), while the following description of the sclerotia would serve equally well for those on ground nut or cow pea—

"A section of the sclerotia reveals them as compactly woven masses of swollen irregular hyphæ. They are entirely devoid of any special epidermal structure, false epidermis or rind, the peripheral structure being identical with the interior."

The account of the sporogenous stage agrees closely with that of the basidiomycete on the ground nut.

Stevens and Hall identify their fungus as *Hypochnus ochroleucus* Noack, they do not make any mention of the similarity of the hyphæ and sclerotia to those of *Rhizoctonia.* A comparison of their paper, however, with that of Rolfs, and with the present memoir

can leave no doubt as to the identity of the fungus on apple with that on potato and ground nut.

It is difficult to say whether *Hypochnus* or *Corticium* is the genus to which this fructification should be referred. Clinton (6) first suggested that "the *Corticium* stage is the same fungus described by Prillieux and Delacroix as *Hypochnus solani*." Rolfs, however, investigated this matter and concluding that *Corticium vagum* B. & C. more nearly represented the fungus, he named it *C. vagum* B. & C. var. *Solani*. In a review of this paper Laubert (17) revived the suggestion that the fruiting stage is not *Corticium vagum*, but the nearly related *Hypochnus solani*, which he described as occurring in connection with *Rhizoctonia* on *Melilotus alba*. The spore measurements given in this memoir agree closely with those of Rolfs; as, however, those of *Hypochnus ochroleucus* and *H. solani* are much the same size, this point is hardly diagnostic. It seems not improbable that all three species are really only one fungus on different hosts; in this connection it is interesting to note that some writers doubt whether there is any distinction between *Hypochnus* and *Corticium*. On the whole, since the description of *Corticium vagum* by Berkeley and Curtis antedates that of *Hypochnus solani* by Prillieux and Delacroix, we are inclined to accept Rolfs' identification.

There remains to be discussed the connection between the form of *Rhizoctonia* with large sclerotia, and a basidiomycete fruiting stage, and the *R. Solani* Kühn described in the first part of this memoir. In both cases the vegetative hyphæ are similar, but the sclerotia differ widely in origin, structure and size. Kühn in his original description of *R. Solani* makes no mention of the large sclerotia at all, and moreover in our cultures the two forms remained perfectly distinct for a year, behaving as separate species.

Rhizoctonia violacea Tul., however, is described (Prillieux 22) as possessing two distinct forms of sclerotia, microsclerotia, agreeing with the small black sclerotia identified in this memoir as *R. Solani* Kühn, and macrosclerotia, resembling the large brown sclerotia which occur in association with *Corticium vagum*. The species of *Rhizoctonia* which Rolfs (24) identifies as *R. Solani* Kühn possesses macro-

sclerotia, but there is no mention of microsclerotia in his paper. It is difficult to understand therefore on what grounds the American *Rhizoctonia* on potato can be identified as *R. Solani* Kühn. If both these sclerotia really belong to one fungus, then the creation of *R. violacea* Tul. as a collective species, possibly including *R. Solani* Kühn, would be justified ; the evidence contained in this paper, however, is decidedly against this view. Cultures and inoculations of the microsclerotia always gave microsclerotia, cultures and inoculations of macrosclerotia either produced macrosclerotia or the fertile *Corticium* stage. Additional evidence showing that the two sclerotia are really distinct is furnished by the work of Stevens and Hall and of Eriksson.

Stevens and Hall (26) describe macrosclerotia in association with the *Corticium* stage on the apple, but they do not make any mention of microsclerotia. Again, judging from the description and figures in Eriksson's paper, the fungus on carrot, which he considered to be *R. violacea*, possessed typical *Rhizoctonia* hyphæ and the small blackish brown microsclerotia, but here again there is no mention of macrosclerotia. Thus in two cases investigators working with one form have failed to mention the other, a fact which is hardly credible if the original conception of *R. violacea* is correct. In some cases (*e.g.*, ground nut and cow pea) both forms may occur on the same host, and indeed it was their association on the saffron which led Tulasne to attribute them to one fungus.

Assuming that two distinct fungi are present, and that the species *R. violacea* Tul., like many other botanical species, is a composite one, the question of the identity of the macrosclerotial form with any known species of *Rhizoctonia* remains to be settled. Certain points of resemblance were noticed between this form and *R. destruens* Tassi, which occurs on the roots of *Delphinium* in Italy, otherwise none of the known species seem to resemble it very closely. On the whole, perhaps the simplest and most convenient solution of the difficulty would be to retain the name *R. violacea* for the macrosclerotial form. While, therefore, the fertile stage of the macrosclerotial form is *Corticium vagum*, that of the microsclerotial, which

is identified here as *R. Solani* Kühn, has yet to be discovered. It is possible that *Rhizoctonia* is a form-genus in which are included the vegetative stages of widely separate fungi; if this is the case, there may yet be some truth in the observations of those investigators who have attributed other fructifications to this fungus.

APPENDIX.

Agar Medium A.—

Agar	15 grms.
Ammonium nitrate	10 ,,
Calcium sulphate	5 ,,
Magnesium sulphate	1 ,,
Lactic acid	2 ,,
Water	1,000 c.c.

Agar Medium B.—

Take 20 seeds of ground nut, grind them up in a mortar and boil with 150 c.c. of water for two hours, allow to stand for 24 hours, decant the supernatant liquid and filter, add water up to 500 c.c.

Agar	7·5 grms.
Aqueous extract of ground nut	500 c.c.

Agar Medium C.—

Take 5 prunes, extract the stones and boil the prunes in 100 c.c. water for 5 minutes, add water up to 500 c.c.

Agar	7·5 grms.
Extract of prunes	500 c.c.

Agar Medium D.—

Agar	15 grms.
Ammonium nitrate	10 ,,
Calcium sulphate	5 ,,
Magnesium sulphate	1 ,,
Glucose	20 ,,
Water	1,000 c.c.

Agar Medium E.—

Extract of Lemco	4 grms.
Sodium chloride	5 ,,
Peptone	10 ,,
Glucose	20 ,,
Agar	15 ,,
Water	1,000 c.c.

Agar Medium F.—

Take 50 grms. of finely ground French beans, boil with 10 c.c. of water for one hour, and filter through a wire gauze tea strainer. Add 10 grms. agar and water up to 500 c.c., boil and filter through linen cloth.

Agar Medium G.—

Boil 30 grms. of agar with 1 litre of water for 30 minutes, also 9 grms. Salep with 1 litre of water for 30 minutes. Mix the two together and add the following :—

1 grm. Grape sugar.

2 grms. Monopotassium phosphate.

Trace Ammonium nitrate.

,, ,, sulphate.

,, Ferric sulphate.

,, Magnesium sulphate.

2 grms. Tartaric acid.

Boil for half an hour and filter in the steriliser (see Mace. E.—Traité pratique de Bacteriologie, Paris, 1889).

Filter Paper.—

Ammonium nitrate	10 grms.
Calcium sulphate	5 ,,
Magnesium sulphate	1 ,,
Lactic acid	2 ,,
Water	1,000 c.c.

Take 50 c.c. of the above solution, add 10 grms. filter paper and sterilise (see Küster, E.—Kultur der Mikroorganismen, 1907, p. 140).

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DESCRIPTION OF PLATES.

PLATE I.

Fig. 1. Young jute plant from field infected with *R. Solani* Kühn*.

,, 2. Healthy seedling of jute.

Figs. 3, 4. Jute seedlings from pot culture inoculated with *R. Solani* Kühn.

Fig. 5. Leaf of cow pea attacked by macrosclerotial form of *Rhizoctonia.*

,, 6. Pod of cow pea from Pusa crop, attacked by macrosclerotial form, young sclerotia appear white, mature sclerotia are brown.

PLATE II.

Fig. 1. Early stage in the infection of cow pea seedling with *R. Solani* Kühn.

,, 2. Later stage of same.

,, 3. Branch completely killed and covered with small black sclerotia.

,, 4. Normal plant.

PLATE III.

Fig. 1. Ground nut seedling infected with *R. Solani* Kühn from cow pea, copious growth of hyphæ at the apex.

,, 2. Ground nut seedling killed by inoculation with *R. Solani* Kühn at the apex, the diseased portion is covered with small black sclerotia.

,, 3. Ground nut plant from the field infected with *R. Solani* Kühn.

PLATE IV

Fig. 1. Cotton seedling inoculated with *R. Solani* Kühn, the small dots on the stem are oil glands, sclerotia have not yet been formed.

,, 2. Cow pea seedling inoculated with *R. Solani* Kühn from cotton plant—abundant sclerotial formation.

,, 3. Ground nut seed, healthy.

,, 4. Ground nut seed infected with *R. Solani* Kühn in pericarp.

,, 5. Cow pea seedling inoculated with macrosclerotial form of *Rhizoctonia.*

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* Unless otherwise stated all figures are natural size.

Plate V.

Fig. 1. Two macrosclerotia of *Rhizoctonia* × 16.

,, 2. Leaf of ground nut attacked by *Rhizoctonia* (macrosclerotial form), the young sclerotia show as white fluffy masses, the mature sclerotia are more compact brown structures.

,, 3. Leaf of ground n· t with two brown sclerotia of *Rhizoctonia* and the white fertile layer of *Corticium vagum.*

,, 4. Stem of the cow pea showing patches of the white sporogenous crust of *Corticium vagum.*

Plate VI.

Fig. 1. Transverse section of outer portion of cortex of a diseased plant of cow pea showing hyphæ of *R. Solani* in tissue. × 375.

,, 2. Transverse section of outer cortex of cow pea inoculated with jute *Rhizoctonia,* cork formation is taking place in the inner layers of the cortex. ph. = phellogen × 375.

Plate VII.

R. Solani Kühn.

Fig. 1. Hypha consisting of short barrel-shaped cells, an early stage in the formation of a sclerotium × 500.

,, 2. Later stage in the same × 1,000.

,, 3. Further stage showing adhesion of lateral branches to main axis × 500.

,, 4. Young sclerotium of *Rhizoctonia* of cotton. It is still possible to trace the course of the original parent hypha × 375.

Plate VIII.

R. Solani Kühn.

Fig. 1. Sclerotia and hyphæ of the cotton *Rhizoctonia* from an agar culture × 300.

Figs. 2, 3. Hyphæ from a culture made on filter paper in a solution of cane-sugar × 500.

Plate IX.

Fig. 1. Microphotograph. Transverse section of sclerotia of *R. Solani* Kühn on the cow pea, the disintegrated tissue of the host can be seen surrounding the sclerotia × 400.

2. Microphotograph. Transverse section of sclerotia of *R. Solani* Kühn on the cotton plant × 375.

Plate X.

Fig. 1. Hyphæ of *Rhizoctonia* (macrosclerotial form) from leaf of ground nut incubated in moist chamber for 24 hours × 500.

,, 2. Mature basidium with spores from leaf of ground nut × 1,000.

,, 3. Spores showing early stage of germination × 1,000.

Figs. 4, 5. Fertile basidia and spores from cow pea × 1,000.

Plate XI.

Fig. 1. Microphotograph. Transverse section of a macrosclerotium of *Rhizoctonia* × 62.

,, 2. Transverse section of stem of jute plant showing hyphæ penetrating the wood × 400.


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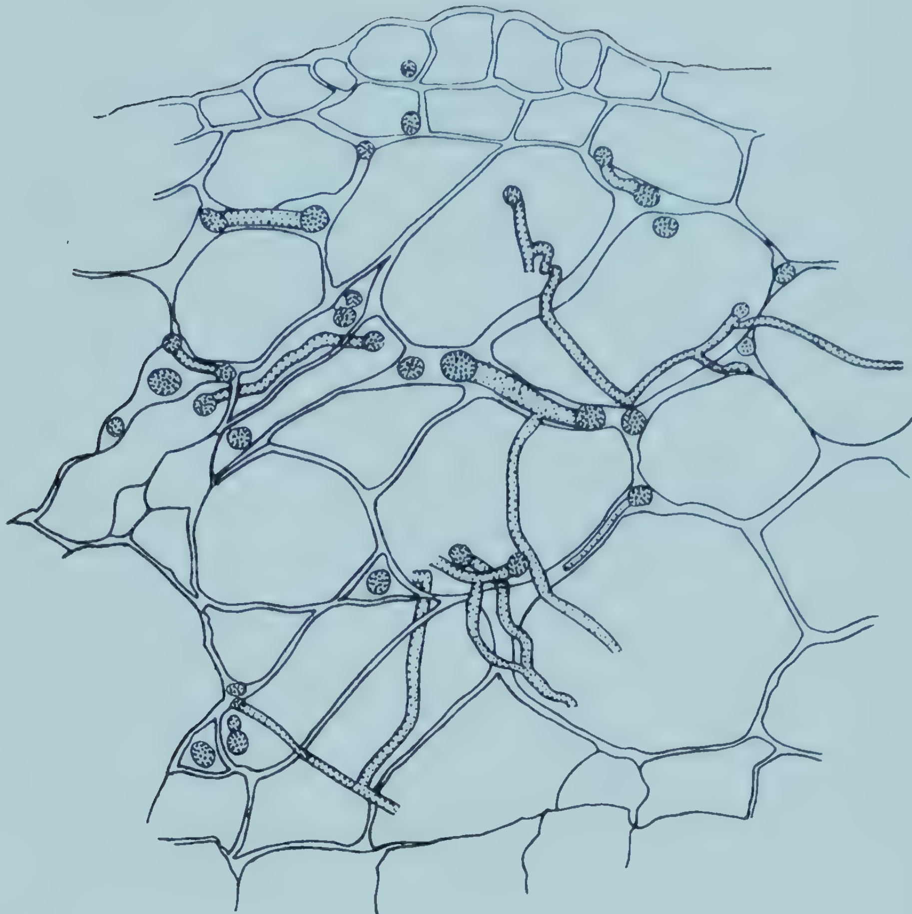

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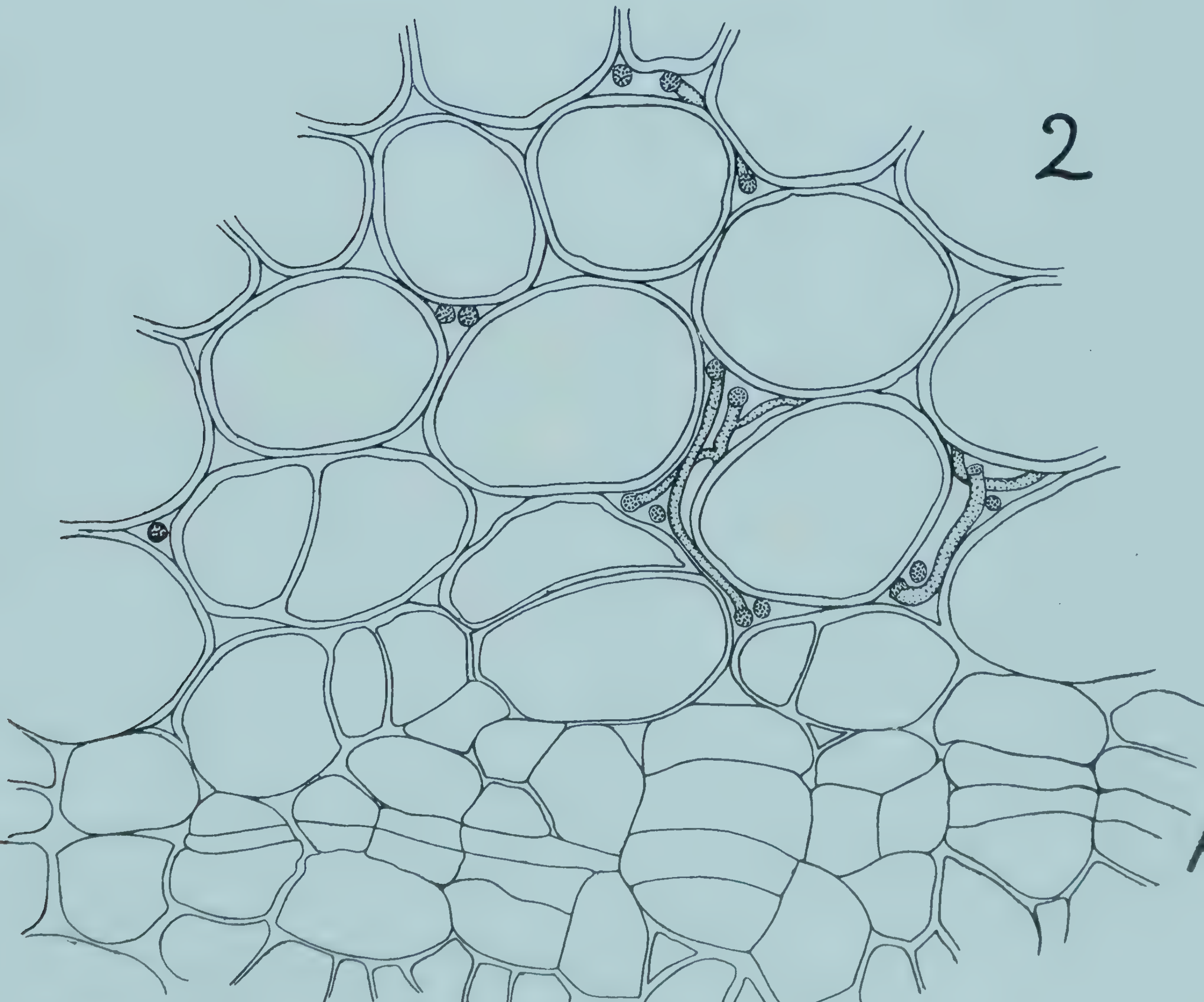


2

K.D.Das

PLATE VII.

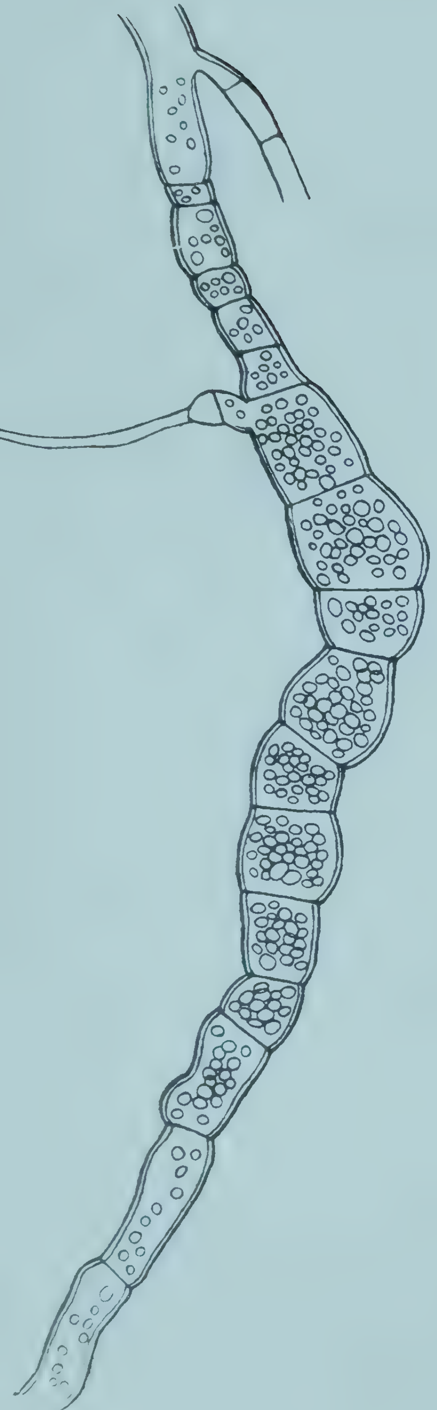


Fig. 1.

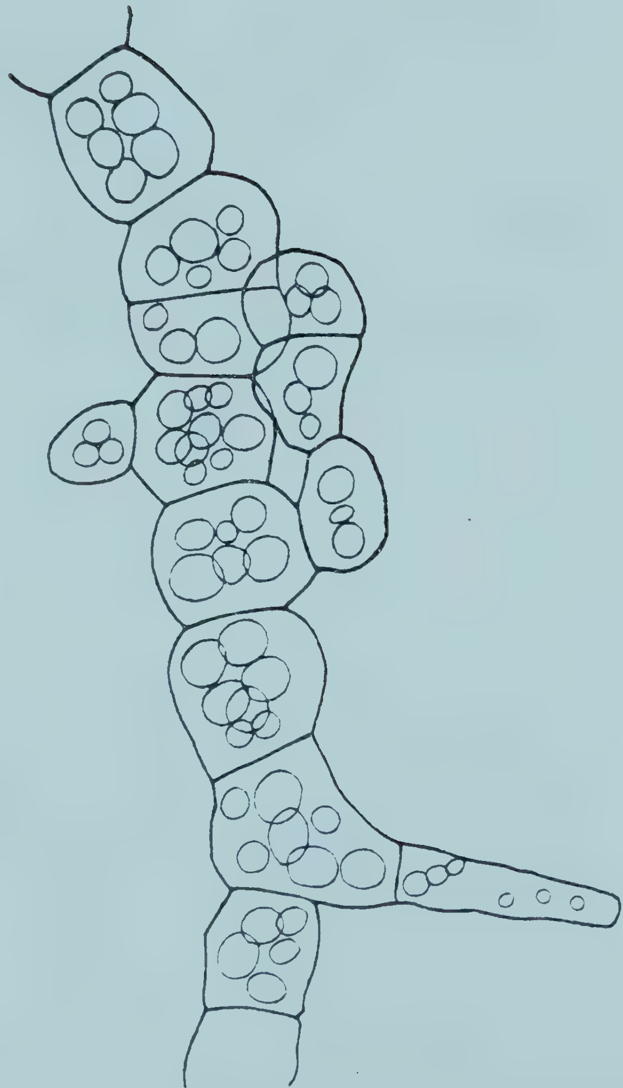


Fig. 2.

Fig. 3.

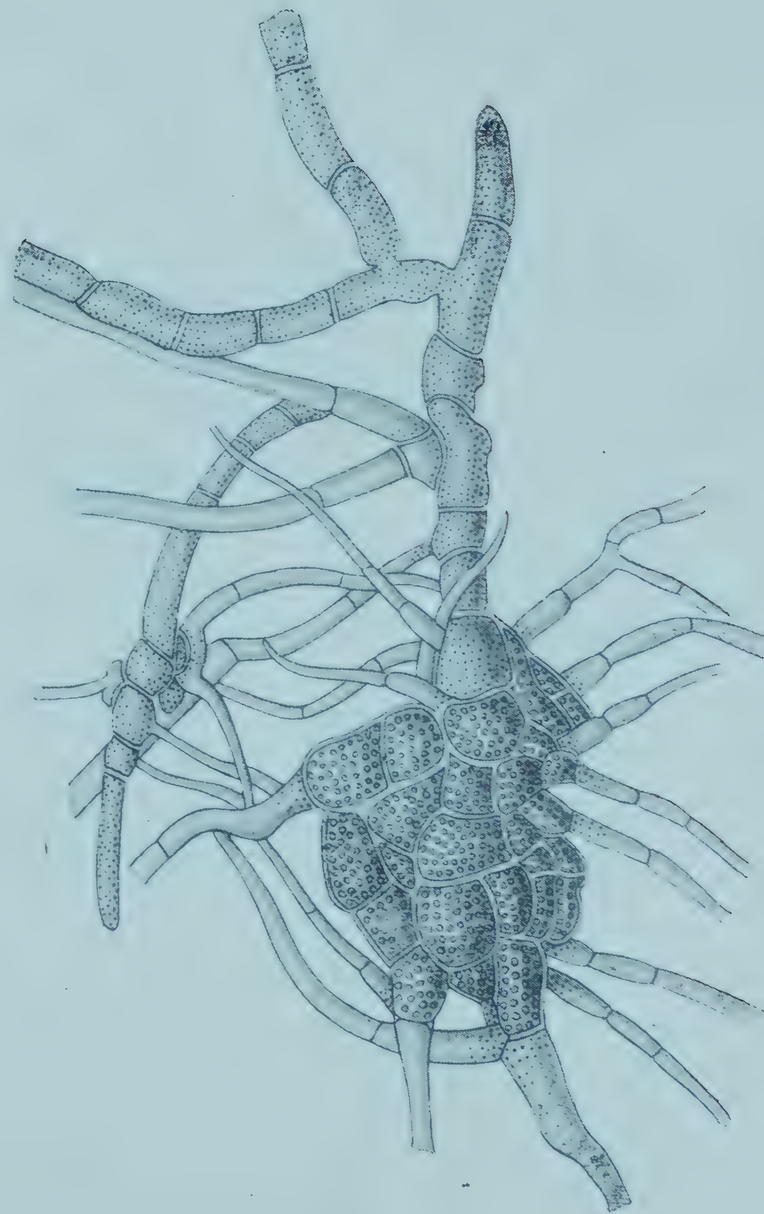


Fig. 4.

PLATE VIII.

FIG. 1.

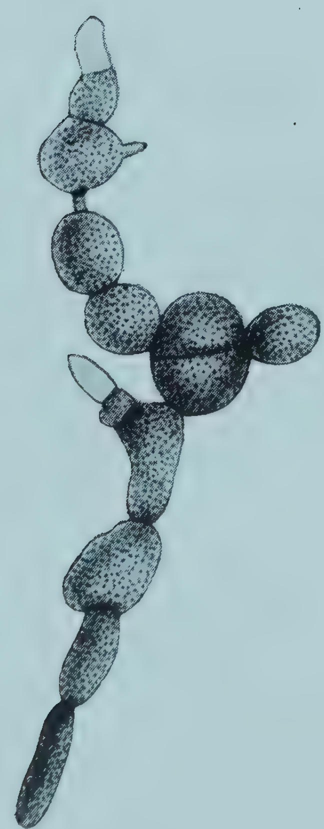


FIG. 2.

FIG. 3.

PLATE IX.

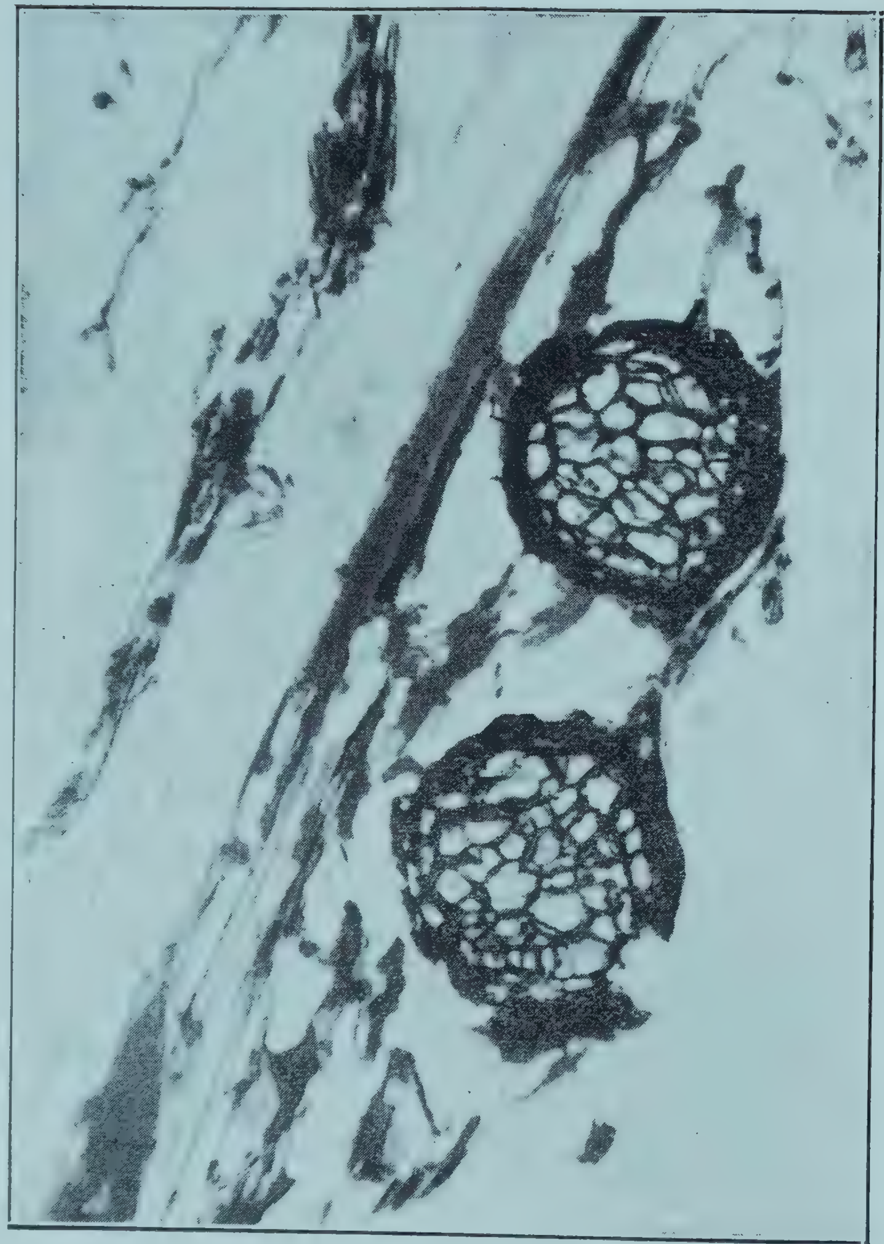


FIG. 1.

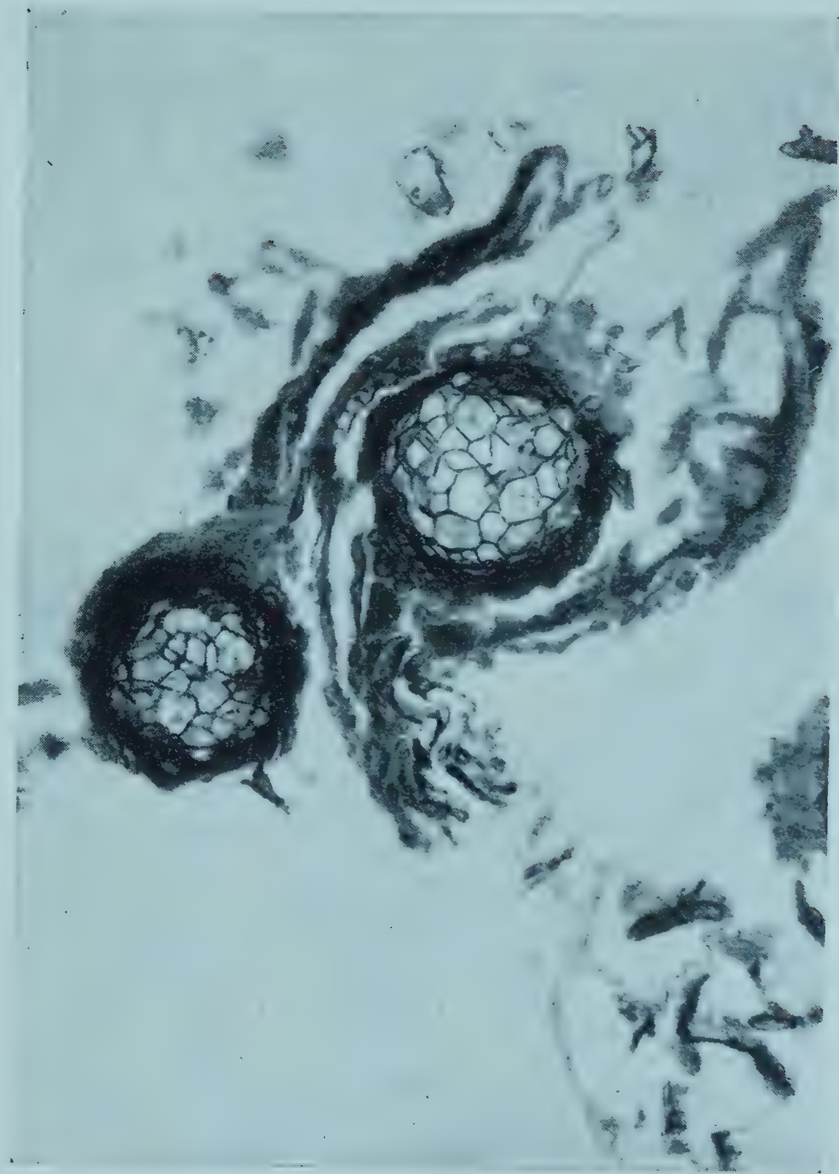
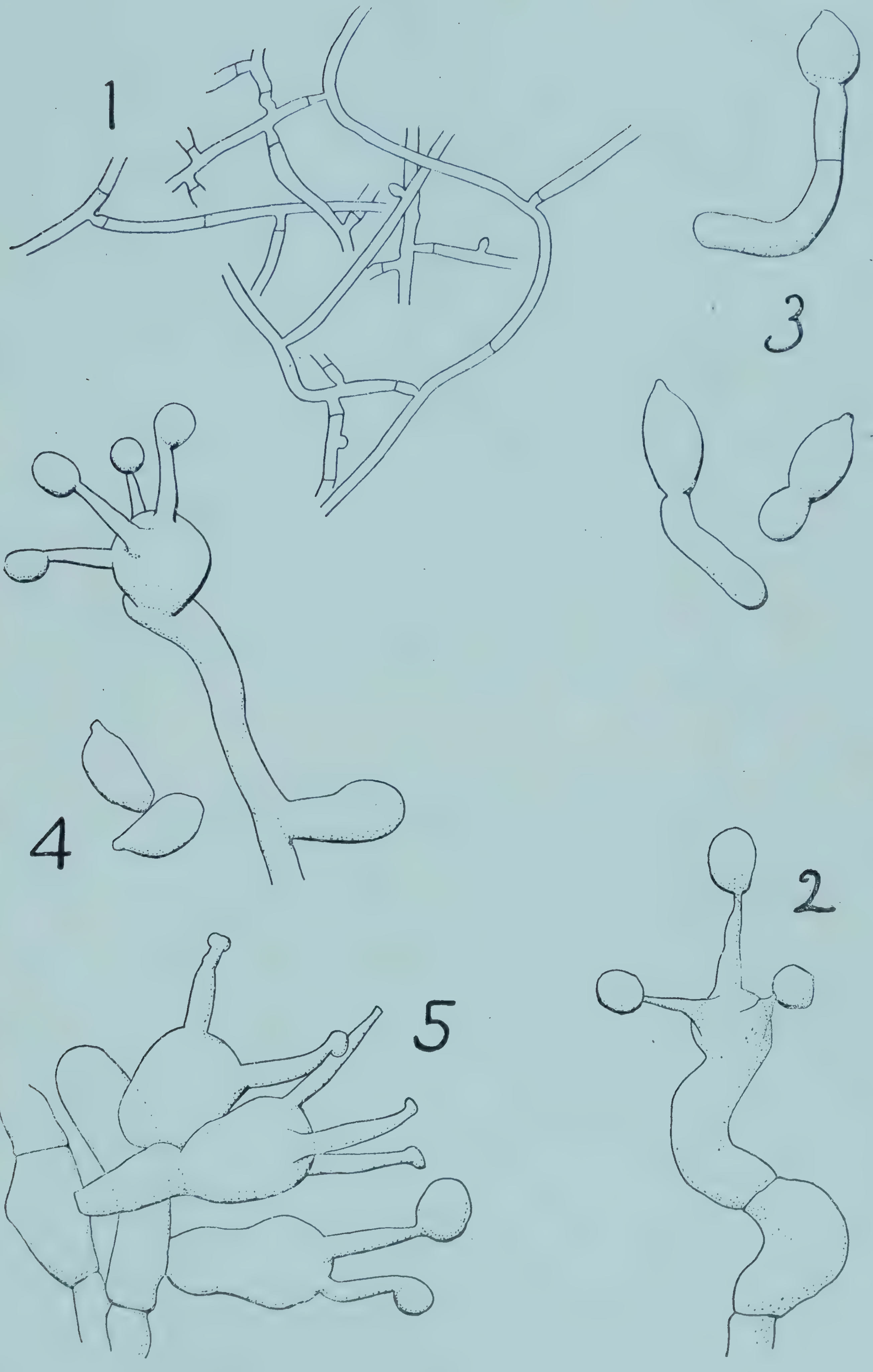


FIG. 2.

PLATE X.



K. D. Das.

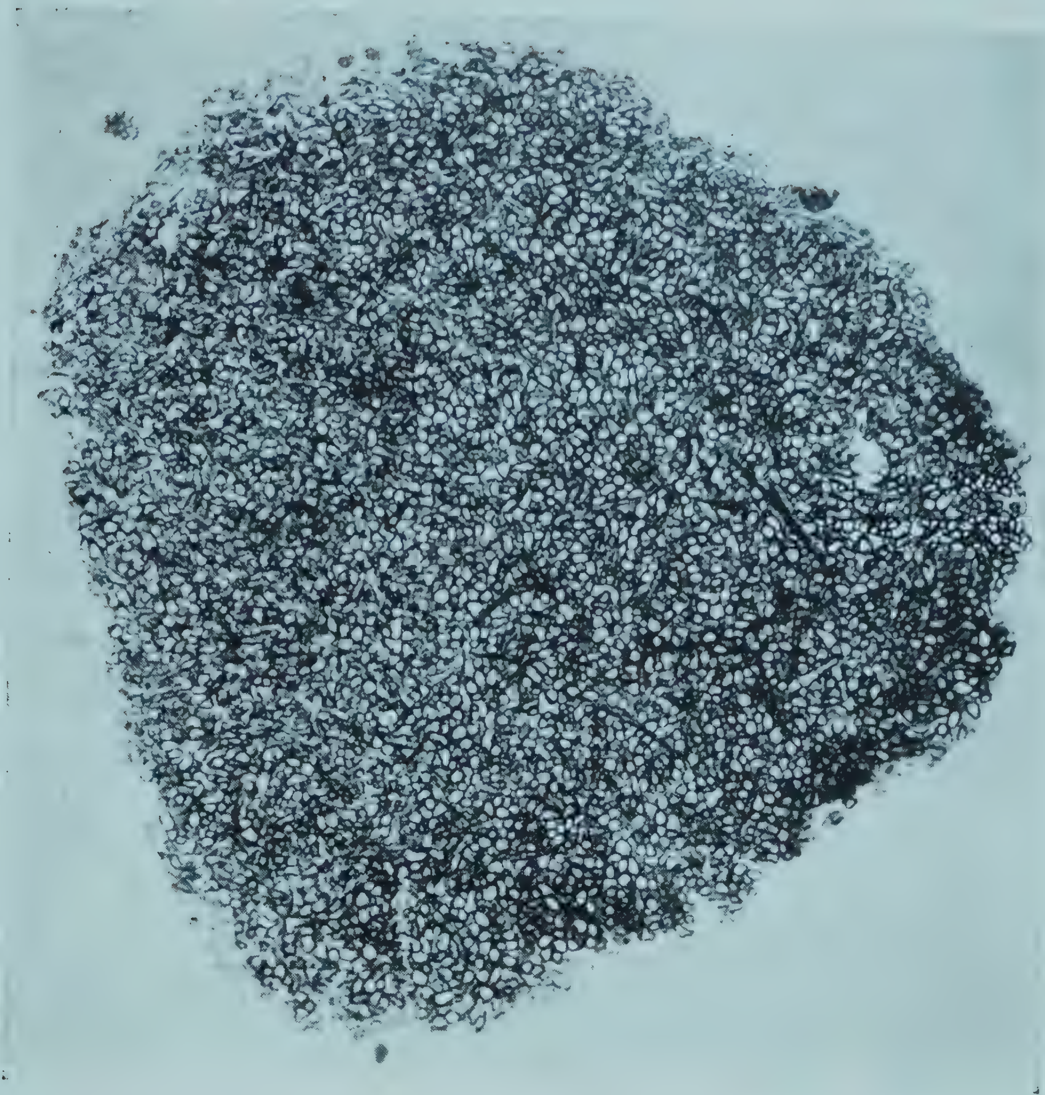


Fig. 1.

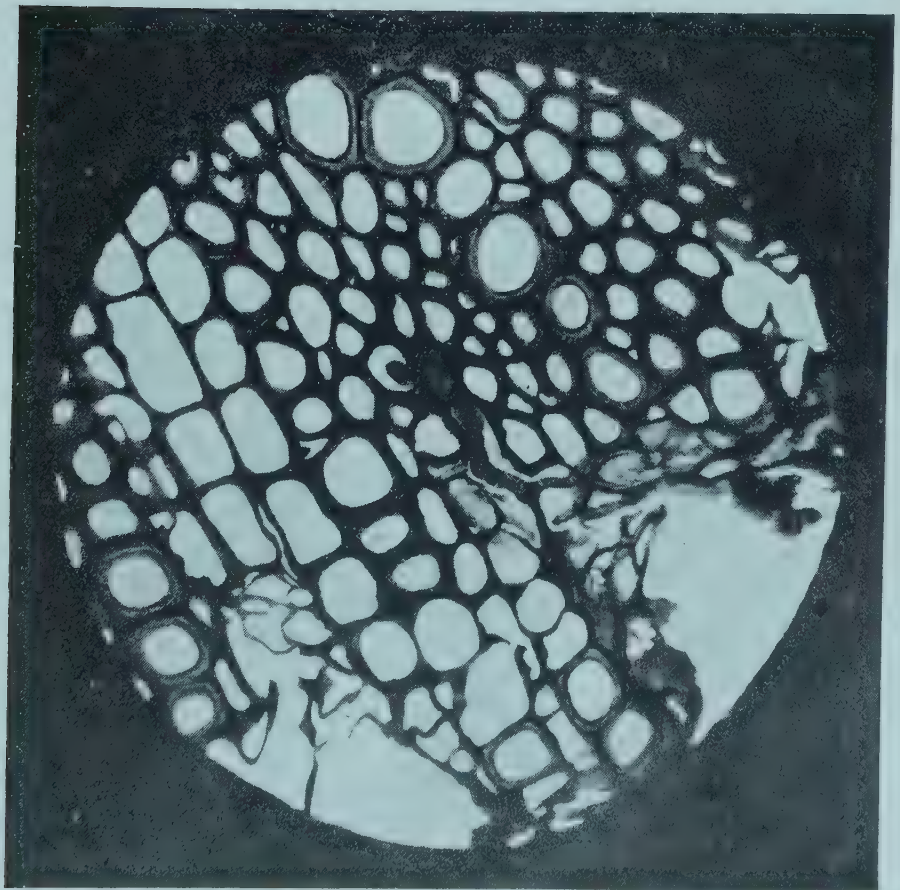


Fig. 2.